Turning the tide on climate change

A potential for major improvements in energy efficiency

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) released in 2007 presented the global community with several reasons for concern and a clear conclusion that warming of the climate system is unequivocal. Global average air and ocean temperatures are increasing, snow is rapidly melting and global average sea level is rising. The Fourth Assessment Report found that most of the increases in global average temperatures since the mid-20th century are very likely due to the observed increase in anthropogenic (caused by human activities) greenhouse gas (GHG) concentrations. Even with current climate change mitigation policies and related sustainable development practices, all indications are that global GHG emissions will continue to grow over the next few decades. This continued anthropogenic reinforcement of the greenhouse effect could lead to very negative impacts worldwide, including the increased occurrence of extreme precipitation events, heatwaves, floods, droughts and other natural catastrophes.

In order to combat the potentially catastrophic effects of climate change, the development of innovative technologies is essential. As stated in the Fourth Assessment Report, there is high agreement and much evidence that stringent efforts to reach GHG stabilization levels can be initiated by the deployment of technologies that are either currently available or expected to be commercialized in coming decades.

The chemical industry can play a major role in tackling the challenge of climate change by developing solutions that reduce energy consumption. Through the development of new technologies, the chemical industry has the potential to bring about a major improvement in the energy efficiency of every sector of the economy.

I therefore warmly welcome the publication of this book written by Robert Kandel and sponsored by Cefic. A native New Yorker and Harvard graduate in astronomy, Kandel is emeritus senior scientist at the Laboratory of Dynamic Meteorology (LMD, *Ecole Polytechnique, Palaisseau*). In addition to his research and lectures at *Ecole Polytechnique*, he has served and continues to serve on numerous national, European, and international science councils, steering committees and working groups. He was awarded the Prix Roberval in 1990 and a Prize of Scientific and Technical Culture of the Ministry of Education, Research and Technology (France) in 1999.

In this book, Kandel details some of the innovative solutions that the chemical industry can contribute to the solution of the myriad problems raised by climate change in a range of fields such as insulation, farming products, lighting, and vehicle manufacturing.

Kandel's book provides a call to action to the chemical industry. Through the development of innovations that would improve energy efficiency, the chemical industry has the potential to move to the forefront of both mitigation and adaptation efforts. Kandel's book is a step in the right direction. I encourage the industry to seriously practise what it preaches.

Dr. Rajendra K. Pachauri
Chairman, Intergovernmental Panel on Climate Change

Combating the greenhouse effect, a joint responsibility

This book authored by Robert Kandel is the starting point for a new paradigm that favors global approaches to combat the greenhouse effect. The underlying study for this work (Innovations for greenhouse gas reductions, 2009) highlights the energy usage and energy savings associated with a wide range of chemicals used in major applications for our everyday activities. Our primary needs – for shelter, food, transportation, *etc.* – all involve energy usage. They also involve a *"hidden"* energy component, however: the energy that is indeed saved through energy-efficient means of transportation, housing or food production.

Reading the book enables us to verify the accuracy of what we intuitively knew, and which technology it has indeed been possible to put into practice. Agriculture, construction, the automotive and aerospace industries have already made extensive use of the chemical resources available, in order to produce performance improvements, including energy efficiency.

Chemicals relate to their uses just as bricks do to houses, and this work tells the story of chains of value, the story of materials interacting to add value and function, and becoming a part of man's response to climate change.

I would like to stress the importance of considering complete lifecycles, looking at systems as a whole. This implies quantifying all the sources of greenhouse gas emissions, from the fossil fuels and raw materials used to produce the *"building blocks"*, to the human activities for which the products are used.

This holistic view of our planetary home will enable us to work towards a more sustainable world. Mr Kandel's book does not simply provide a static snapshot but views the chemical industry as being at the heart of the greenhouse effect issue, presenting a new way of seeing, and shaping the future. New possibilities are opening up for us, where chemistry and chemical researchers will naturally play their role: bringing their knowledge and expertise to meet new needs.

The examples presented provide good illustrations of the joint responsibility and need for collaboration between all the players that is essential to curb greenhouse gas emissions. The energy scenarios suggested for 2030 partly depend on solutions that chemistry makes possible. For them to come about, we need creativity, open minds, and technological and business capabilities.

Each link in the sequence of industrial production and human activity must ensure a source of added value, with energy efficiency more than ever a key factor. It is my fervent hope that this book will help educate us to a holistic view that is able to show us the path forward, providing us with a real industrial ecology to achieve global greenhouse gas emission reductions.

Christian Jourquin
President of CEFIC, European Chemical Industry Council

Turning the tide on climate change

The climate change challenge and the chemical industry

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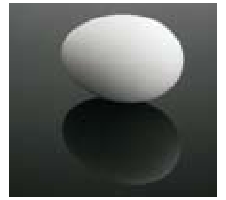


Human industrial and agricultural activities are changing climate, a vital aspect of our environment on earth. To avoid dangerous climate change, we need to make our activities more compatible with the natural processes that govern climate. We must begin to reduce emissions of greenhouse gases over the globe. Is such a change of course, essential for sustainable development, compatible with economic growth? As shown in the United Nations 4th IPCC (Intergovernmental Panel on Climate Change) Assessment Report, ambitious emissions reductions *can* be implemented at modest cost (less than 3% reduction of global wealth production by 2030), with measures having net negative costs (which means in fact benefits).

The chemical industry has a responsibility in the emission of greenhouse gases, but it also produces materials providing essential services while reducing greenhouse gas emissions. The challenge for the chemical industry as for society is to go further in that direction. With McKinsey, the International Council of Chemical Associations has carried out a study of how this can be done. The move to a low-carbon economy (emitting less carbon dioxide and other GHGs), progressively reducing and ultimately phasing out dependence on non-renewable resources, must be seen as a challenging opportunity. This requires pursuit and expansion of research and development in all material science, and in the advanced chemical industry.

The European Chemical industry has shown strong performance in that respect. At the same time, the international framework for greenhouse gas emissions abatement, now under construction, must ensure that carbon reduction is global.

The ICCA Report: what are the messages?

Innovations for Greenhouse Gas Reductions. A life cycle quantification of carbon abatement solutions enabled by the chemical industry

The International Council of Chemical Associations (ICCA) commissioned McKinsey for a report on the global chemical industry's impact on greenhouse gas emissions through the life cycle of key chemical products and the applications they enable. This report can help industry, stakeholders and policymakers understand the role of the chemical industry as enabler of solutions to "decarbonize" the economy and highlight the chemical industry's potential to help the world further reduce GHG emissions. The report found that for every unit of greenhouse gases emitted by the global chemical industry to produce these chemicals, the industry enabled more than 2 units of emission savings via the products and technologies provided to other industries or users, if compared to the non-chemical solutions. It also shows that depending on the regulatory and economic conditions this impact can be increased.

The main messages of the ICCA report are:

- *Many chemical products are net reducers of CO_2-emissions; without chemistry, GHG emissions would be greater. Thus, chemistry is a key solution provider in climate protection.*
- *A global carbon framework has to avoid market distortions. As long as there is no global carbon framework, the trade-exposed chemical industry needs transition free carbon allowances. That system of rights to emit carbon would be granted to enable them to implement reduction measures without facing an unfair competition with regions that would not have set such binding regulations.*
- *Governments should continue to promote research and development.*
- *A technology cooperation mechanism between the developed and the developing world should be established, while safeguarding intellectual property rights. As such, the ICCA report deals with a global chemical industry. However, considering the dangers of too rapid climate change, it is absolutely essential to encourage the EU-based chemical industry in its efforts to reduce GHG emissions and to safeguard the industry's position in a competitive and innovative economy.*

Note:

The ICCA report focuses on the Energy / Carbon life cycle, taking into account all greenhouse gas emissions in terms of carbon dioxide equivalence. Although an important aspect of Life Cycle Analysis, this is definitely not the only environmental factor. The scientific basis of the report has been validated by the Öko Institut, an independent research organisation of Germany.

An introduction to the climate change paradigm

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- A global policy framework drives intense discussions. What consequences for our lives?
- The UN recommendations are issued from a long series of studies and discussions on climate change.
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- Climate change: are we sure to know what we are talking about?
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A global policy framework drives intense discussions. What consequences for our lives?

The UN recommendations are issued from a long series of studies and discussions on climate change. They have more material to fix specific targets

The Intergovernmental Panel on Climate Change (IPCC) wrote a first assessment that led to the United Nations Framework Convention on Climate Change signed at the 1992 *"Earth Summit"* at Rio de Janeiro. It established machinery for national inventories to keep track of these emissions. The 1997 Kyoto Protocol established for the first time quantitative targets for emissions reductions applying to industrialized countries, but not to less developed countries. It came into force in 2002, following ratification by the European Union, Japan, and the Russian Federation, despite withdrawal of the U.S. signature by the Bush administration. The European Union committed itself to reducing GHG emissions by 8% (by 2010, and modulated by country) relative to the 1990 level. Although more ambitious emissions reductions targets have now been announced in the EU and elsewhere, *e.g.* by the United States administration, putting together a potential working framework of international governance, starting at Copenhagen in December 2009, will be an arduous task.

The European Union wants to give the example of commitments. How to be sure they are sustainable?

European Union countries expressed concern about climate change in the 1989 summit at The Hague. At Kyoto (1997), they exerted pressure for strong emissions reductions targets. The EU-15 members, faced with difficulties in meeting their commitments for an overall 8% reduction from 1990 to 2010, and conscious of the need to go further, have begun to develop new mechanisms (*e.g.* carbon emissions rights trading) with the ambition of a factor four (*i.e.* 75%) reduction in GHG emissions in the next few decades. The 1997 Club of Rome report argued that with (then) existing technology, twice as much wealth could be produced with half the resources, hence the factor four. The EU-27 framework now includes regions still in transition to a market economy, where economic growth needs to be established on a less *"carbon-emissive"* base.

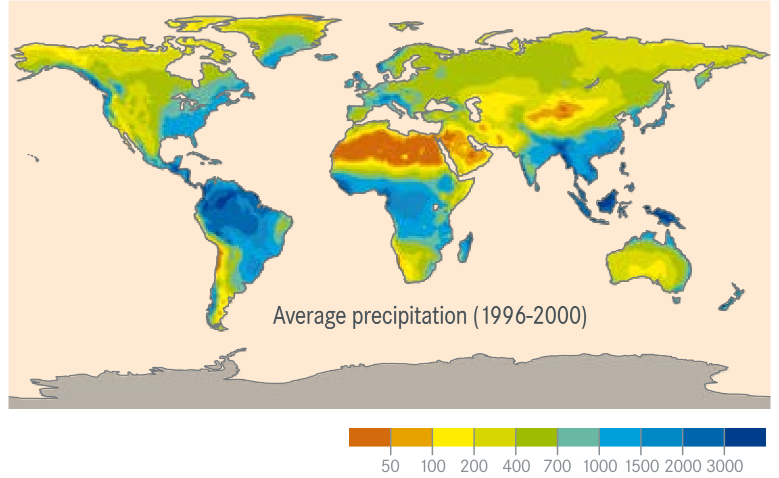
For the EU-27, reducing the *"carbon footprint"* goes along with reducing dependence on imported fossil fuels. Ensuring that such reduction takes place without *"carbon leakage"* by import of products made elsewhere with high GHG emissions goes together with protecting employment and manufacturing capacity in Europe. In general, carbon leakage is about shifting production from low-GHG-emitting regions to regions with high emissions and no measures limiting them to ensure climate protection; import of products from such regions is only the second step. For EU institutions, avoiding a trade war while meeting adequate commitments is essential for sustainable European growth.

Why is there a need for discussion and action on climate change issues?

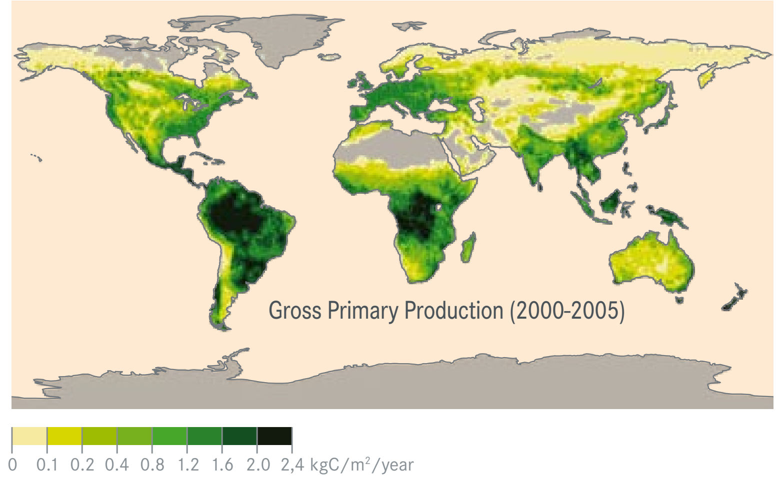
What is climate?

The climate change issue is often subsumed under the title *"global warming"*. In terms of everyday life, however, climate usually refers to local or regional physical and chemical conditions that prevail at or near the Earth's surface. These conditions include atmospheric and surface temperatures, atmospheric pressure, humidity, wind, cloud cover, solar and infrared radiation fields, the state and amount of surface and near-surface water, evaporation, precipitation (rain, snow) and horizontal freshwater flows (runoff). Although the conditions at or near the surface define the climate that we humans live with, they depend also on conditions at higher layers in the atmosphere, as well as in the soil and under the sea surface.

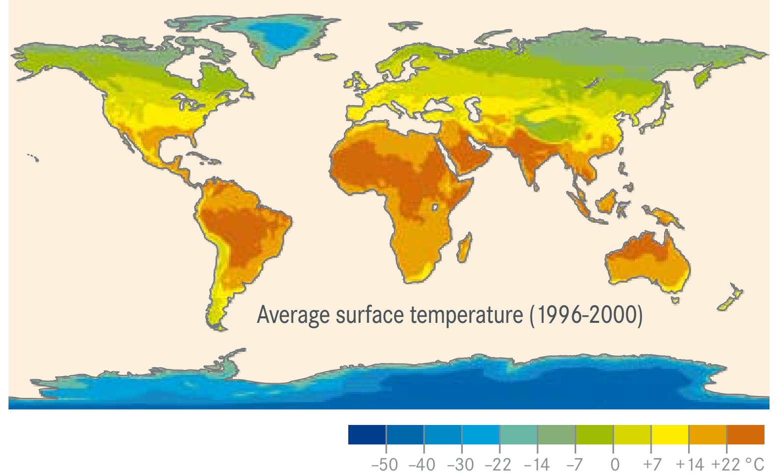
As a global climate parameter, the global annual mean surface air temperature has a value of +15°C that distinguishes Earth as a planet on which water exists in a liquid state. For life on land, in addition to mean surface temperature one must add a measure of the global water cycle (evaporation or precipitation), or better, an average of the water fluxes (evaporation, precipitation, runoff) over all land surfaces. Still, the notion of a global climate is a caricature of the complexity of climate's geographic structure.



Average precipitation (1996-2000)

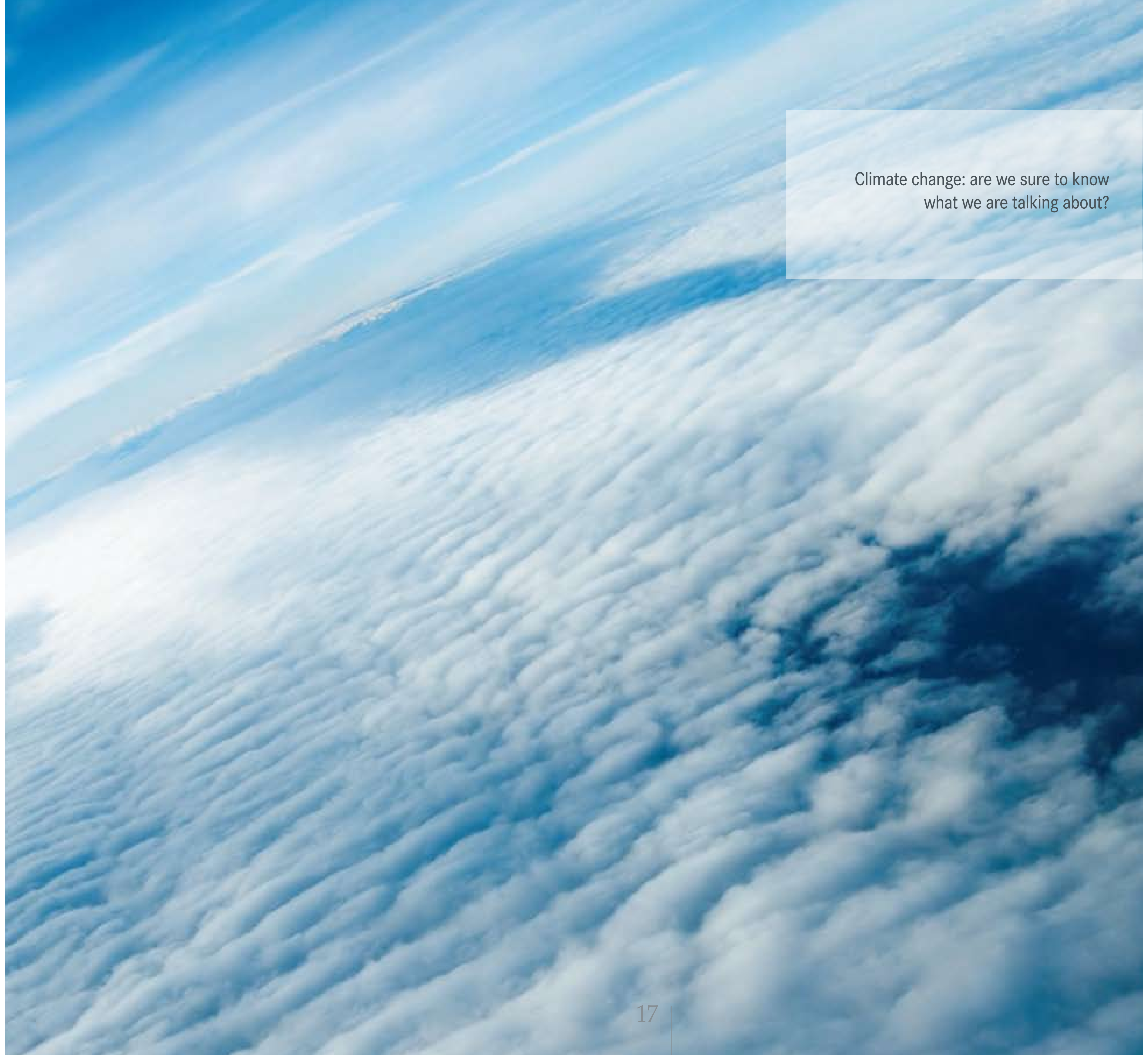


Gross Primary Production (2000-2005)



Average surface temperature (1996-2000)

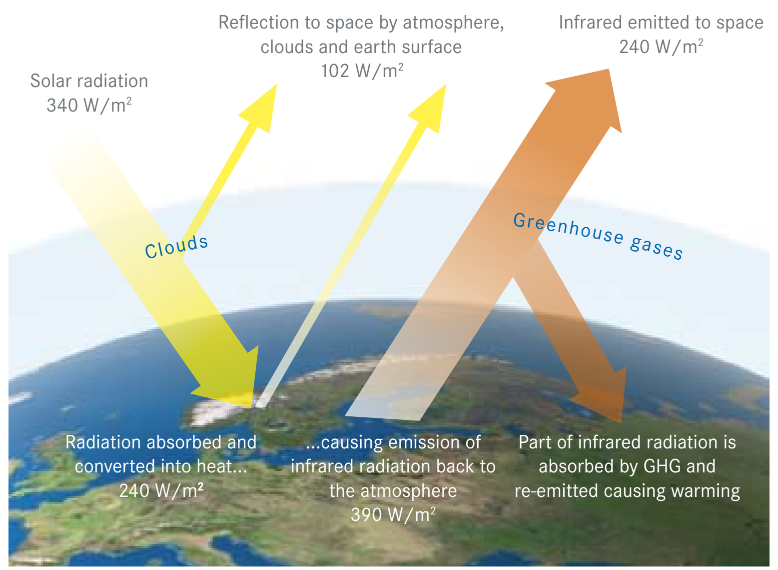
Climate conditions and their geographical distribution are all-important for life on land, as can be seen by comparing a map of temperature, water availability, and available sunlight, with a map of primary production (grams of carbon produced per square meter per year), measuring the process of photosynthesis by which green plants use sunlight, water (H_2O) and carbon dioxide (CO_2) to make the more complex carbon-based molecules on which life depends. Present-day life requires on the one hand a minimum of the atmospheric CO_2 that constitutes an essential raw material for photosynthesis, on the other hand the atmospheric oxygen, maintained by photosynthesis, on which animal life depends.



Global climate control factors

Climate depends on three factors. **The first** is the flux of incoming energy from the Sun, **the second** the fraction that is reflected to space (the planetary albedo or *"parasol"*). The remaining fraction is converted to heat and must return to space as thermal infrared (*"heat"*) radiation. **The third factor**, the *"greenhouse effect"*, determines the surface temperature that gives global energy balance. In principle, each of these three climate control factors can vary and so cause climate change. Observations from space since the 1970s show that solar flux has varied only by 0.1% with an 11-year cycle. The parasol factor has shown no significant trend. However, the greenhouse factor depends on the composition of the atmosphere.

Earth's energy balance and the greenhouse effect



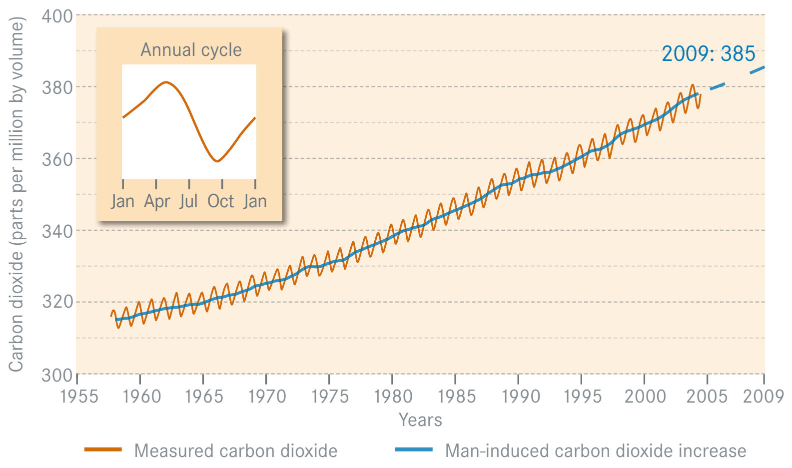
Antropogenic greenhouse gases emission contribute to global warming by increasing the proportion of infrared radiations re-emitted to earth.

Observed changes in atmospheric composition

Significant increases have been observed in atmospheric concentrations of carbon dioxide (CO_2), methane, nitrous oxide, and other gases made up of polyatomic molecules (*i.e.* molecules made of 3 or more atoms). Together with water vapor (H_2O) and clouds, these gases absorb thermal infrared radiation emitted upward by the Earth's surface, and re-emit part of it downward as well as upward. This constitutes the natural greenhouse effect, which maintains much of the Earth's surface at the *"comfortable"* average temperature of +15°C at which water can exist in the liquid state.

Increases in atmospheric greenhouse gases, in particular CO_2, *intensify* the natural greenhouse effect and so tend to further warm the surface. These increases are clearly *anthropogenic, i.e.* due to human pastoral, agricultural, and industrial activities.

Atmospheric carbon dioxide, measured at Mauna Loa (Hawaii) since 50 years



The unit, parts per million by volume, corresponds to cubic centimeters of carbon dioxide per cubic meter of air. The annual cycle at Mauna Loa reveals natural uptake of carbon dioxide by Northern Hemisphere land vegetation during the growing season, release the rest of the year when respiration dominates. The cycle is reversed, with the seasons, in New Zealand data. No cycle appears at the South Pole, far from any vegetation.

Source: R.F. Keeling et al. - Scripps Institution of Oceanography.

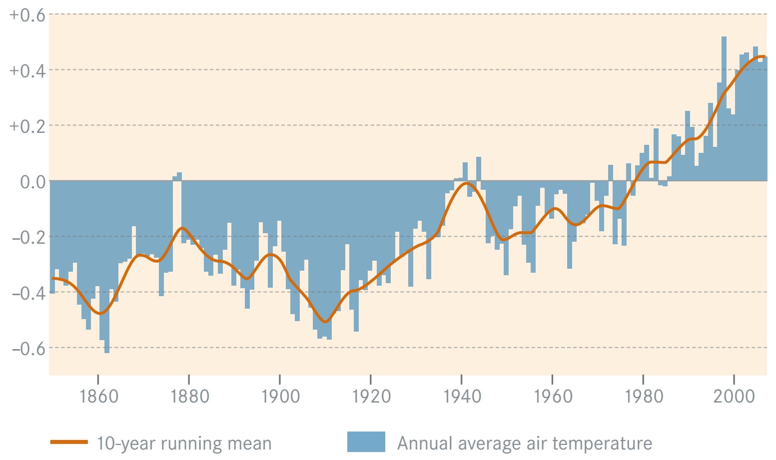
The accelerating increase in atmospheric CO_2 results mostly from burning of fossil fuels (coal, petroleum, natural gas) for production of energy, heating, and transport.

Observed Climate Change – Global Warming

There is a global warming trend since 1900. Warming was fairly strong from 1910 to 1940, followed from 1940 to 1970 by a period of stagnation with slight Northern Hemisphere cooling while warming continued in the Southern Hemisphere, and accelerating global warming since 1970. Comparing 2007 to the period (1961-1990), the map of annual mean surface air temperature reveals warming almost everywhere over the globe. Although 2008 was the coolest year since 1997, it was warmer than all years from 1850 to 1996.

Observed changes in global average surface temperature

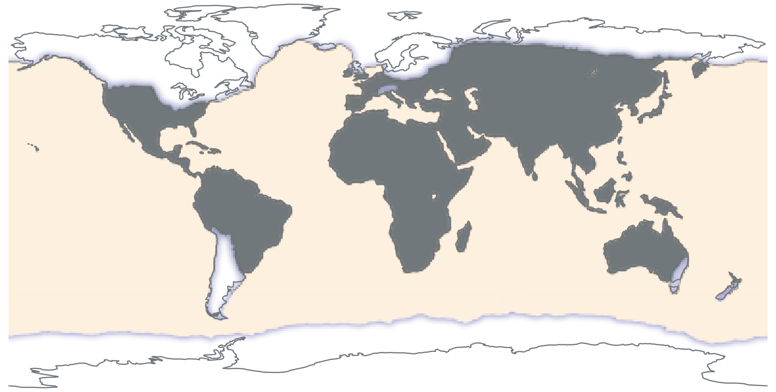
Differences are relative to corresponding averages for the period 1961-1990



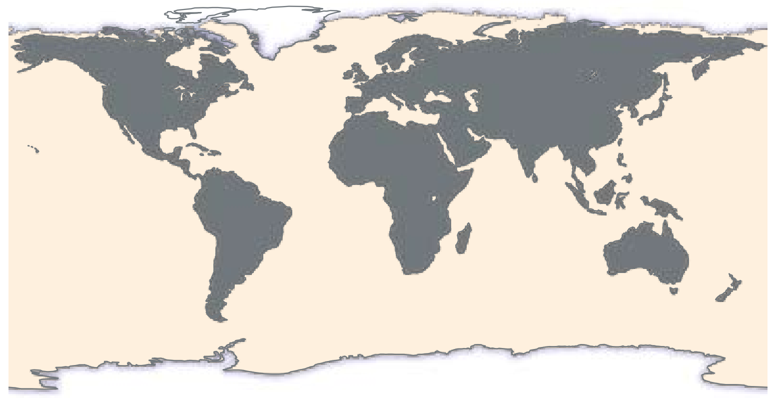
Based on Brohanet al. (2008)

Natural variation of ice cover

Maximum extend during last glacial period (18,000 years ago)



Nowadays extend

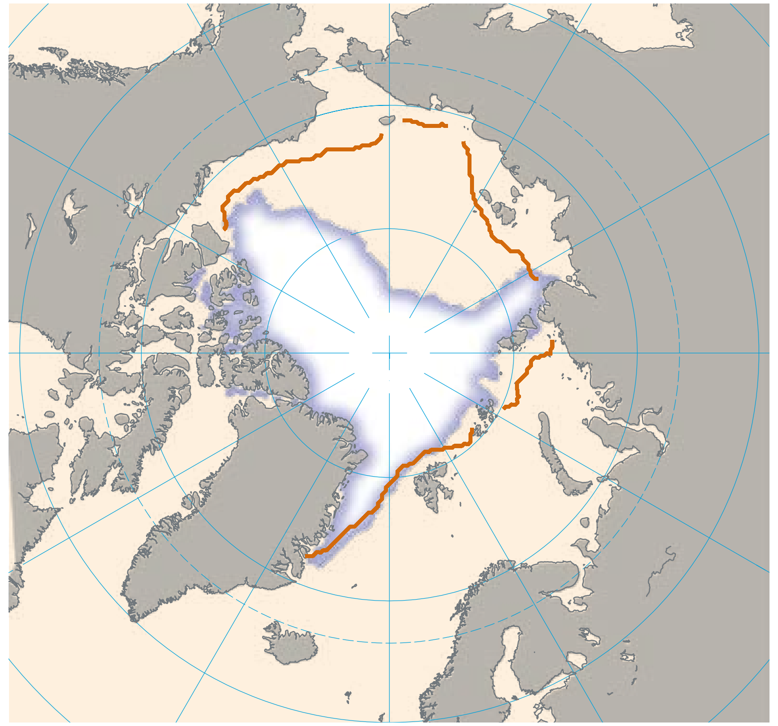


To go back further into the past than 1850, climatologists use indirect evidence from a variety of sources – wine harvest dates, underground temperatures in deep boreholes, pollen trapped in peat... The warming of the last half-century is different from earlier fluctuations. Temperatures today have reached levels as high as or higher than those of the past two thousand years. Over the past million years, the Earth went through several very cold periods (ice ages), with ice covering much of North America and northern Europe. The last glacial maximum took place only 18,000 years ago. Milder interglacial periods such as the present one that was established by 10,000 years ago, with low-altitude ice cover restricted to the Arctic and Antarctic polar zones, have recurred about every 100,000 years and lasted between 10,000 and 20,000 years.

These variations were natural. Research has generally confirmed the *"astronomical"* theory developed by Milankovitch in the first half of the 20th century: glacial-interglacial climate variations are driven by well-understood small semi-periodic changes in the shape and orientation of the Earth's orbit and in the orientation of its axis of rotation. But observations of the last century, and especially of the last few decades, reveal accelerating climate change that does not fit into that picture.

Why is there a need for a low-carbon society?

Evolution of sea ice surface area on the arctic ocean



Average sea ice in September 1979-2000 Sea ice coverage on 16 September 2007

Based on Spreen et al (2007) and data from the National Snow and Ice Data Center

Observations of risks and current events

Model-based projections for the remainder of the 21st century are no simple extrapolations of global warming trends of past decades. In computer models of the climate system, the established laws of nature – Newton's laws, the laws of conservation of matter and energy... – are translated into computer language and applied to realistic schematizations of the Earth's atmosphere, surface, and oceans. Such projections also involve scenarios about the influence of economic and technological development in the world on GHG emissions.

Even if greenhouse gas concentrations could be immediately stabilized, the world would continue to warm because of excess heat already trapped in the oceans. The strengthening greenhouse effect could well produce global warming of more than 2°C during this century, with stronger warming on the mid-latitude continents, notably in Eurasia and North America, and changes in operation of the water cycle. It has been generally agreed that with such warming, the world will enter the zone of dangerous climate change. To avoid it, global GHG emissions must begin to decline by the year 2030.

The climate changes summarized as global warming involve changes in the geographical distribution of surface temperatures, the means and the variability. Very high temperatures (like the European heat wave of summer 2003), could become common by the end of this century. In any event, the warming trend affects the distribution of different types of vegetation. Changing climate changes distributions of freshwater availability and frequencies of extreme events, ranging from extended droughts, to extreme rainfall events producing floods, to violent storms. It will have increasing impacts on the natural as well as the managed biosphere (agricultural land, pasture and managed forests). In some regions crop yields will rise, but in others they will fall to levels so low as to trigger mass migration.

Warming has major impacts on the receding mountain glaciers, which store and regulate freshwater supply. Their disappearance will have serious consequences, from agriculture to operation of hydroelectric and thermal power plants. Warming of the ocean has begun, and because the warming seawater expands, this has already led to sea-level rise. Continuation of ocean warming due to the imbalance of the planet's energy budget will increase the sea-level rise, (it could reach 60 cm by the end of the century), mostly because of the thermal expansion of the warmed ocean layers.

Another appearing major impact is on ice in polar regions. Melting of floating sea ice has no effect on sea level. But the freshwater presently in the form of solid ice on land corresponds to a potential sea-level rise of more than 60 meters. Most of this is on the Antarctic continent, but a significant amount is in the Greenland ice cap. Melting or collapse of land-based ice in Greenland or Antarctica would lead to rapid sea-level rise, possibly more than a meter before the end of the century. This would flood many densely populated and unprotected low-altitude coastal regions. In any event, even modest sea-level rise exacerbates saltwater intrusion in coastal aquifers and raises the risks from storm surge.

All of these physical impacts, and others, investigated by the United Nations Intergovernmental Panel on Climate Change (IPCC), have strong impacts on the natural biosphere as well as on the agricultural, pastoral and industrial activities of human societies. How much will it cost? Up to what level of effort should we go? According to some analyses, the potential economic cost of these impacts is great, whereas the costs of mitigation (reduction of GHG emissions) are smaller if not in themselves negative (*i.e.* directly beneficial). Some economists, for example William Nordhaus, have contested the discount rate used in the widely publicized Stern Report, arguing that it projects high future climate change costs and requires expensive immediate mitigation measures without taking into account the possibility of less costly mitigation in the future.Others have emphasized that the unacceptable costs of some possible climate changes render the usual discount-rate approach inappropriate.

The International Council of Chemical Associations report implicitly recognizes some aspects of this problem in evaluating GHG emissions abatement costs, distinguishing between the perspectives of *"business"* (interest rate 10%, depreciation over 10 years) and *"society"* (4% interest rate, depreciation over equipment lifetime, often several decades). Can the short-term *"business"* perspective, subject to global competitive constraints, ignore the low-probability but extremely-high-cost risks? but extremely-high-cost risks?

As noted in the *World Bank's World Development Report 2010*, although *"Nordhaus settings"* give an optimum peak CO_2 target (750 parts per million, a volume indication known as ppm) substantially higher and thus easier to avoid exceeding than the (540 ppm) target calculated using *"Stern settings"*, the cost of aiming for the lower GHG peak target is very small (0.3% of present consumption) and can be considered as inexpensive insurance against damaging climate change.

For the most part, the IPCC impact assessments are based on projections of gradual albeit accelerating climate change, and do not take into account the possibility of abrupt severe climate change. With improved tools for exploring the record of past climates, researchers have found many examples of strong climate changes over periods of a decade or less. As explored in the 2002 report of the (US) National Academy of Sciences, and as noted in the 2007 CNA (US) study report on *National Security and the Threat of Climate Change, "Such abrupt climate changes could make future adaptation extremely difficult, even for the most developed countries."*

Human origins of present-day climate change

Climate today is changing, with well-established global and regional warming trends. Other aspects of climate, like the water cycle and the frequencies of certain extreme events, also are changing. Increases in atmospheric greenhouse gases intensify the natural effect and so tend to further warm the surface.

Human activities are reinforcing the greenhouse effect

The warming trends of the last century, considered as much stronger than climate fluctuations of the past two thousand years, have appeared together with the sharp increases in atmospheric concentrations of the greenhouse gases CO_2 and methane. Those increases have no precedent in the preceding million years. Indeed the rise in atmospheric CO_2 due to human activities, most of which has taken place in the last 50 years, is stronger and much faster than the natural rise of CO_2 that took place over a period of more than 5,000 years at the end of the last ice age.

Attributing global warming since 1950 to the rise of CO_2 is not simply a matter of correlation. The well-established physics of the transfer of radiation in the atmosphere tells us that although it is not the only factor affecting climate, this rapid reinforcement of the greenhouse effect perturbs Earth's energy balance. As a result, mean surface temperature is rising

What about other natural climate factors?

Variations of the Sun have been too weak to explain the climate changes of the past century, but what about the *"parasol effect"*? The planet's albedo (the fraction of the Sun's incoming radiation reflected or scattered back to space) determines what fraction of incoming solar radiation is converted into heat. Volcanic eruptions increase the amount of reflecting particles in the stratosphere (altitude 10-50 km). Powerful eruptions have caused global cooling, as in 1816, the *"year without a summer"* that followed the 1815 eruption of Tambora in Indonesia. The eruption of Mount Pinatubo in the Philippines in 1991 led to a brief pause in global warming. The effects of such eruptions can be strong, but they last less than two years, while reinforcement of the greenhouse effect has been growing year after year.

What about pollution?

In addition to the invisible and odorless greenhouse gas CO_2, burning of fuels often leads to easily perceived pollution by particles. For wood as well as for coal or oil, this can be in the form of unburned carbon – soot and black smoke. And when thermal power plants or factories burn coal or oil containing sulfur, the gas sulfur dioxide is produced, then transformed into aerosols (particles suspended in the air) and acid rain. Such pollution, apart from its direct effects on health, vegetation, and buildings, also affects reflection or absorption of solar radiation. However, in Europe and generally in the middle latitudes, particles tend to be rained out within a few days. Unless particles reach the stratosphere (10-50 km altitude), they do not stay in the atmosphere very long. As a result, their effects tend to be regional rather than global, and they do not accumulate. Efforts to reduce such pollution pay off quickly. In Europe and in North America, sulfur dioxide emissions have been much reduced since the 1970s, in part by shift to natural gas, in part by installation of catalytic converters (*"scrubbers"*) using chemical industry products. And in Asia, once serious efforts are made, most of the particles in the air will disappear in a few years.

For the most part, particles have a *cooling* effect by reducing sunlight reaching the surface. However, black carbon particles absorb solar energy, warming the air at altitude. Where they fall on snow or ice, they strongly warm those surfaces in summer. Overall, the effects are smaller than the greenhouse effect intensification, and because the particles do not accumulate indefinitely in the atmosphere, their effects cannot grow the way the greenhouse effect has been growing.

Conclusion

Analysis shows then that intensification of the greenhouse effect by human activities constitutes is a *growing* perturbation of the Earth's energy balance, stronger than any of the natural perturbations, much stronger than the weak (0.1%) *cyclical* variation of the Sun, stronger than the global mean effect of pollution with particles, and most of the time stronger than the *temporary* reductions, due to volcanic eruptions, of solar energy reaching the surface.

The observed warming of surface and lower atmosphere is consistent with reinforcement of the greenhouse effect. So is the measured penetration of the warming in the ocean. As the lower atmosphere warms, its absolute humidity increases, further intensifying the greenhouse effect, amplifying the warming due to the direct anthropogenic increase of CO_2 and other well-mixed GHGs. Some uncertainties remain, regarding how different types of clouds and of precipitation change. However, the consistency of predicted and observed warming is strong.

28 The global impact of anthropogenic CO_2 and other GHG emissions

- Anthropogenic emissions
- Carbon dioxide
- Methane
- Other anthropogenic greenhouse gas emissions
- The need for a strategy to ultimately reverse the *"global warming"* trend

40 The need to invest in a new way of living and working

- What are the principal sources of anthropogenic GHG emissions?
- Agriculture
- Manufacturing
- Residential and office building sector
- Transport
- Energy and carbon intensities
- How can the growing energy demand be balanced against the need to reduce GHG emissions?
- An example of a solution?

The global impact of anthropogenic CO_2 and other GHG emissions: essential elements of life to be managed with care

Observations and physical analysis have led to the scientific consensus that reinforcement of the greenhouse effect by human activities is the dominant cause of current climate change (IPCC AR4). What are these greenhouse gases? What are their main sources?

Anthropogenic emissions, *i.e.* emissions originating in human activities (mining, industry, agriculture, animal husbandry, deforestation, heating, mobility and transportation), have strongly increased the amount of certain GHGs in the atmosphere

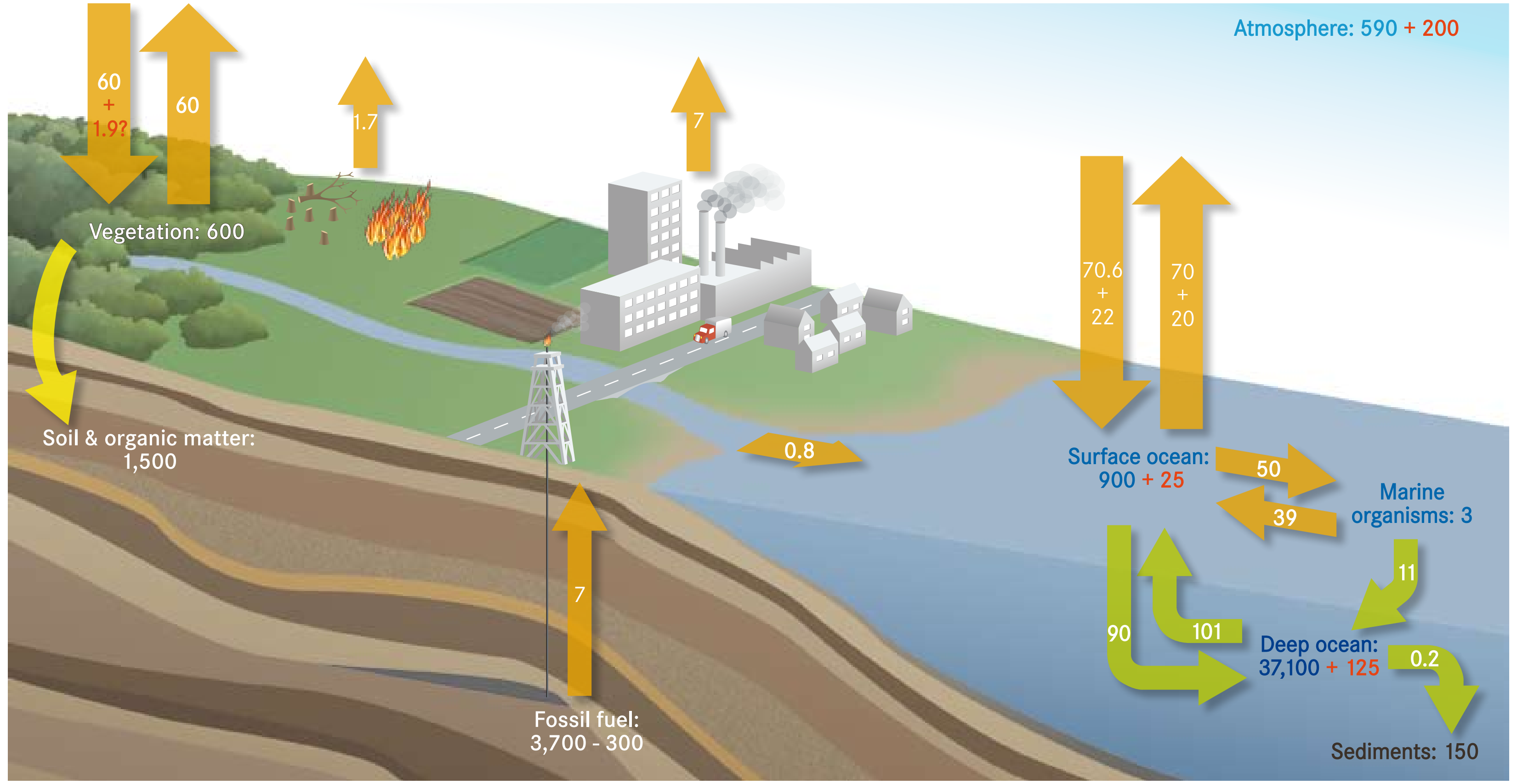
Carbon dioxide

In 1896, Swedish chemist and Nobel-Prize laureate Svante Arrhenius hypothesized that carbon dioxide emissions due to fossil-fuel (then mostly coal) burning would change the atmosphere's CO_2 content. In 1900, global carbon dioxide emissions were roughly 1.8 billion tons per year; by the 1950s, they had been multiplied by four. Also, significant CO_2 emissions resulted from deforestation, with burning of vegetation in cleared land and oxidation of soil carbon. Important in the 19th century in North America, this intensified in the 20th century in the tropical zone.

By the year 2000, however, anthropogenic CO_2 came mostly from fossil-fuel burning, with continued growth in burning of coal and strongly increased emissions from burning of petroleum products and natural gas. Globally, over 25 billion tons of CO_2 were emitted in 2000 from burning fossil fuels. That corresponds to a global *average* of about 4 tons of CO_2, or well over a thousand litres of fuel, per person per year. The average for Europe (EU-27) is over twice as high. Although still smaller than the natural fluxes exchanged between atmosphere and ocean and between the atmosphere and the land biosphere, the *growing* anthropogenic emissions have strongly unbalanced the planet's carbon cycle, as is clear from the changes in atmospheric CO_2 content.

The Carbon Cycle

Carbon contents (billion tons) and carbon fluxes (billion tons/year) in the Earth system



Fast processes - years or less   Slow processes - 100 years

The estimate is 600 billion tons of carbon in vegetation, 1,500 billion in soils and organic matter, 3,700 billion as fossil fuel (and much more in other deep sediments), and 38,000 billion tons in the ocean, with 900 billion in near-surface layers. For the atmosphere, and for fluxes between the atmosphere and the oceans as well as the land biosphere, the carbon is almost entirely in the form of carbon dioxide (CO_2). Between 1750 and the first decade of the 21st century, over 200 billion additional tons of carbon accumulated in the atmosphere, corresponding to over 300 billion tons of carbon removed from underground as fossil fuels (over 7 billion/year since the year 2000) and 120 billion tons coming from deforestation and oxidization of soil. Deforestation sends 1.7 billion tons of carbon per year into the atmosphere, but fertilization of land vegetation by higher CO_2 may be absorbing 1.9.

Between atmosphere and ocean, the blue figures correspond to physical exchange of CO_2, while the red figures are estimates of the carbon fluxes between the atmosphere and the marine biosphere, with 25 billion tons of carbon added to near surface ocean waters and 125 billion tons of carbon added to the deep ocean since 1750. Estimated carbon flux from erosion transported by way of rivers to the sea is also shown.

Sources: Center for climatic research, Institute for environmental studies, IPCC2, UNEP and WMO.

How can one produce tons of carbon dioxide? Some European figures...

All we do in our everyday life contributes to CO_2 production: switching the light on, heating and lighting our homes, driving a car or riding the bus, taking the airplane... even breathing. But how much?

First of all, don't worry about breathing. The CO_2 produced by all oxygen-breathing living creatures on Earth is negligible compared to other natural and human-related sources. On the other hand, for the world and much of Europe, electric power production depends on burning coal, oil, or natural gas, releasing CO_2. If in lighting your home, running your refrigerator, washing machine, television and computer, you consume 1,500 kilowatt-hours of such electric power in a year that could involve over one ton of CO_2.

In 2008, an average European car produces 160 g of CO_2 per kilometer. Therefore, it produces a ton of carbon dioxide for a trip of 6250 km (Brussels-Athens and return). A European drives on average 15,000 kilometers per year (releasing 2.4 tons of CO_2). Therefore, the 220 million European cars released 528 million tons of CO_2 (0.5 billion tons of CO_2 - 0,5 $GtCO_2$).

A modern airplane, such as an Airbus A340, can carry 380 persons using 194,800 liters of fuel to fly 13,900 km. This represents 0.0037 liter of fuel per kilometers and per passenger. In fact, airplanes are not always full and take-off and landing use more fuel, so the average is closer to 5 l of fuel per passenger and per 100 kilometers. On an average long-haul of 6500 km, each passenger then produces 800 kg of carbon dioxide. For domestic flights these values can be up to double! In 2004, intra-EU flights emitted around 52 million tons of CO_2, out of 130 million tons emitted by all EU-departing flights (Source: Eurocontrol). The world total of aircraft CO_2 emissions was about 650 million tons.

Considering all transport in Europe, whether by road, air, rail, or water, nearly one billion tons of CO_2 was emitted in 2005, i.e. over a ton per European.

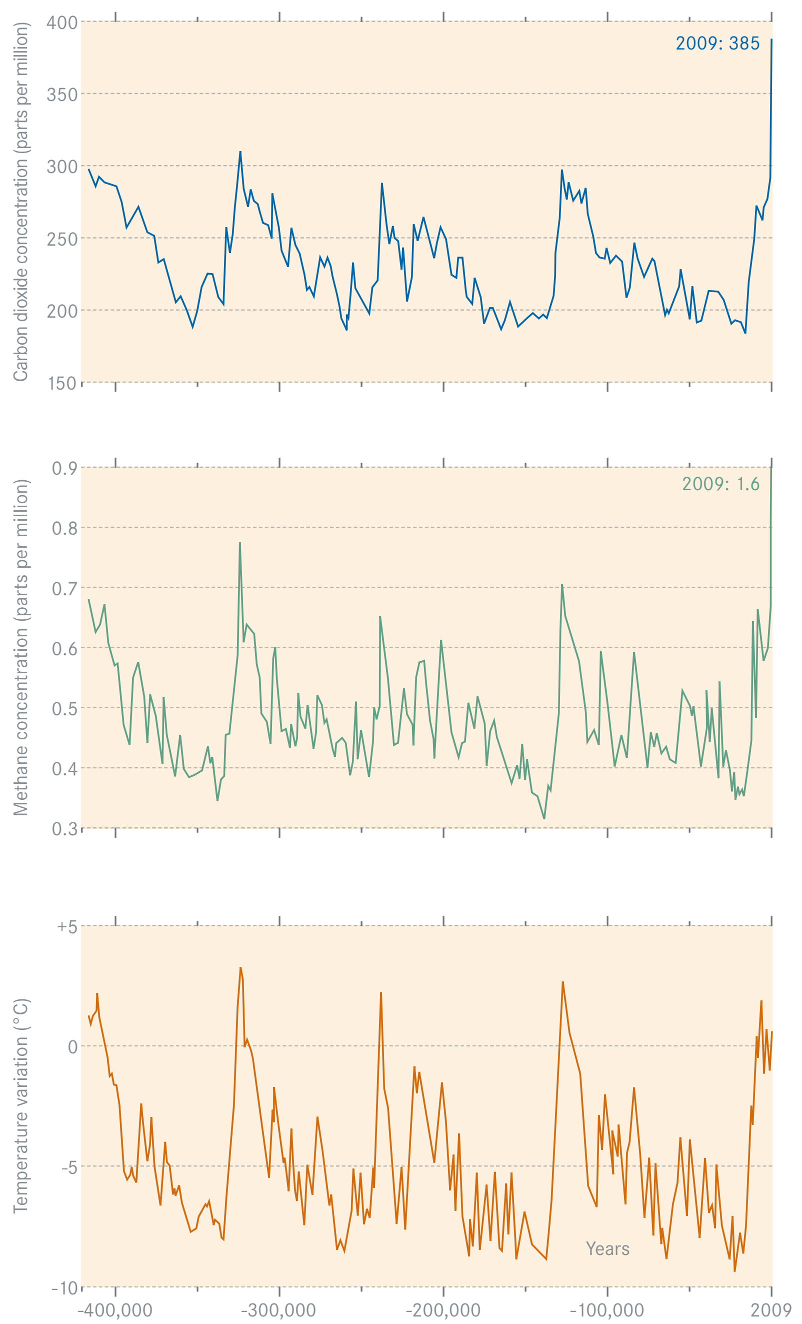
Heating a hundred square meter house may require 18,000 kilowatt-hours producing 8.1 tons of CO_2 per year if fuel, oil or natural gas are used. Using electricity produced by burning coal, oil, or natural gas (with 50% efficiency), CO_2 emissions are twice as large. Not all Europeans live in such large houses, not all can afford to heat so well, some areas require more heating, some less, and some use nuclear- or hydro-generated electricity, or renewable wood. In fact, annual emissions due to heating homes in Europe come to several hundred million tons of CO_2, close to a ton per European.

And of course, producing everything that you buy and supplying many of the services you use involves emissions of CO_2, on average close to 3 tons of CO_2 per European.

Note:

Carbon dioxide emissions are expressed either in terms of carbon dioxide (CO_2) or in terms of carbon, generally in billions of tons (gigatons or Gt) per year. With mass 12 for the carbon atom, 16 for the oxygen atom, the mass ratio of CO_2 to C is simply (12+32)/12 or 3.67.

Evolution of carbon dioxide, methane and temperature over the last 420,000 years



Systematic monitoring of atmospheric CO_2 began with the station set up on Mauna Loa (Hawaii); the measurement series continues today with additional stations all over the globe. These measurements confirm an accelerating trend of increasing CO_2 concentration in the global atmosphere, from 315 parts per million per volume (ppm/v or ppm, or cubic cm of CO_2 per cubic meter of air) in 1957 to 335 ppm in 1975, 385 ppm in 2008. Observed seasonal oscillations correspond to uptake of CO_2 by photosynthesis during the growing season and release of CO_2 by plant respiration the rest of the year.

At the surface, carbon dioxide emissions are often from concentrated sources, but they are *globalized* by the circulation of the atmosphere. Between 1750 and the year 2000, atmospheric CO_2 concentration increased from about 280 ppm to 370 ppm. The total amount of CO_2 in the atmosphere increased from about 2,200 to 2,900 billion tons, reaching nearly 3 trillion tons in 2008. The additional CO_2 accumulated in the atmosphere amounts to not quite half of the CO_2 that was emitted as a result of fossil-fuel burning, deforestation, and oxidation of exposed soils. There is no reasonable doubt regarding the dominant role of human activities since the 1950s.

Going back much further in the past, analyses of ice cores extracted in Antarctica and Greenland tell us that along with the natural climate variations between glacial and interglacial periods, the amount of CO_2, methane (CH_4), and nitrous oxide (N_2O) in the air also varied. However, for the past 740,000 years at least, the range of natural CO_2 variations was between minimum values of 180 ppm at the coldest, and maximum values about 280 ppm at the warmest. Similarly, the natural variations of methane were between 350 parts per billion (ppb or cubic millimeters of methane per cubic meter of air) at the coldest, to 700 ppb during interglacial periods. But for CO_2, methane, and nitrous oxide, the rapid increases of the last two centuries are completely outside the natural range; they result from human activities, as established by rigorous scientific analysis. Considering these and other greenhouse gases, total emissions due to human activities were reinforcing the greenhouse effect with the equivalent (see CO_2 equivalence - page 36) of 46 billion tons of CO_2 in 2005.

Carbon dioxide — Methane — Temperature

Note that the change in carbon dioxide from 290 ppm in 1900 to 385 ppm in 2009, and in methane from roughly 0.7 ppm in 1850 to about 1.6 ppm in 2009 are much much faster than any of the earlier changes, even those that appear very steep on the 400,000-year scale. On this scale, the warming since 1900 hardly appears. Note that the "present" when dates are given as "before present" or B.P. corresponds by convention to the year 1950.

Source: Petit et al. (1999) - Ice core samples from the Vostok records.

Processes ("sinks") removing CO_2 from the atmosphere:
Rapidly increasing emissions to the atmosphere have strongly unbalanced the planetary carbon cycle; at present, the CO_2 in the air is out of equilibrium relative to the amount in the oceans. Several natural processes go in the direction of reducing this imbalance. The substantial increase in atmospheric CO_2 has – so far – led to an increasing net flux of CO_2 from the atmosphere into the oceans, in part by way of the marine biosphere. Today, roughly a fourth of the anthropogenic CO_2 emissions ends up in the ocean. This fraction – the oceanic CO_2 sink – has diminished since 1960, because warming and the rising concentration of CO_2 in ocean waters increase the return flux of CO_2 from the oceans to the atmosphere.

Because CO_2 is a raw material (with H_2O) for photosynthesis, its increase has a fertilizing effect on plants (including algae), intensifying photosynthesis provided that other vital elements (sunshine, water, nutrients) are not lacking. As for the oceans, about a fourth of the anthropogenic CO_2 emissions are taken up by the land biosphere, even though deforestation in the tropical zone reduces capacity there and acts as a CO_2 source. Between tropical deforestation and increasing water stress in some regions, the global land biosphere CO_2 sink fraction has decreased, and according to some calculations, the land biosphere could become a CO_2 source before the end of the century.

What about other factors?
***Oxygen:** For CO_2, the role of fossil-fuel burning, combining carbon with oxygen to form CO_2, is evident. This leads to a reduction in atmospheric oxygen. That is not a cause for concern, because with about 500 times more oxygen (as O_2 molecules) than CO_2 in today's atmosphere, doubling CO_2 would reduce oxygen by only 0.4%, corresponding for example to the rarefaction of air between the street and the 10th floor of a building. But for the greenhouse effect, the relative increase for CO_2 (over 30% since 1900) is significant.*

***Water vapor:** Burning hydrocarbons (for example petroleum and natural gas) yields water vapor (H_2O) as well as CO_2. However, while the additional CO_2 flux is significant, amounting to about 20% of the natural fluxes of CO_2 between atmosphere, oceans, and biosphere, this is not the case for the added H_2O. The natural water fluxes are about 20,000 times larger than the H_2O directly added by burning hydrocarbons. On average, water vapor stays only 8 days in the atmosphere, and so it is not a well-mixed gas: absolute humidity differs strongly from one place to another and varies strongly from one time to another. However, although direct anthropogenic emissions of water vapor are insignificant, water vapor remains the dominant greenhouse gas.*

***Water-vapor feedback:** Warm air can hold more water vapor than cold air before saturation and condensation intervene at (or slightly above) 100% relative humidity. At 35°C, often reached in Europe in the summer, absolute humidity can and usually does get significantly higher than at 20°C, much higher than at 0°C. The frigid air over polar regions can contain only very little water vapor.*

Because of this, global warming affects atmospheric water vapor content even though the direct H_2O emissions from burning of hydrocarbons are negligible. If, on average over the globe, atmospheric relative humidity stays the same, warming of the atmosphere leads to increasing absolute humidity, and the additional H_2O in the air further reinforces the greenhouse effect, amplifying the warming. Satellite observations have confirmed that this effect is indeed operating as a positive feedback in the atmosphere.

***Rising ocean acidity:** As noted above, the oceans have acted as a carbon sink, removing some of the CO_2 added to the atmosphere by human activities. The result of this, however, is to increase the acidity of seawater, because the dissolved CO_2 forms carbonic acid (H_2CO_2). This is already causing some damage to coral reef ecosystems. As emphasized by the Monaco Declaration of oceanographers, there is a risk of irreversible damage if acidity becomes too strong.*

Methane

Methane (CH_4, known as *"natural gas"*) is also strongly affected by human activities. Just as for CO_2, there are natural exchanges between atmosphere, oceans, and the biosphere, but many new sources are involved. Strong methane emissions are produced by certain bacteria living in oxygen-free environments of flooded rice paddies on the one hand and the digestive systems of cattle and other ruminants on the other, produce methane.

Those environments have expanded with the growth of human populations cultivating rice, and with the increase in bovine population due to the rising numbers of meat-eating (as well as milk-drinking) humans. Global methane emissions have increased enormously. Methane is important even though it is far less abundant than CO_2 (today less than 2 ppm compared to 385 ppm CO_2), because it absorbs thermal infrared radiation at wavelengths at which there is very little absorption by the other atmospheric gases. Thus each additional ton of methane in the atmosphere intensifies the greenhouse effect many times more strongly than a ton of added CO_2.

Other anthropogenic greenhouse gas emissions

In addition to CO_2 and methane, human activities have modified soil emissions of the strong greenhouse gas nitrous oxide (N_2O), by way of increasing intensive agriculture aided by chemical nitrogen-based fertilizers. Also to be counted are the GHGs artificially produced since the 1930s by the chemical industry to satisfy consumer needs, in particular the chlorofluorocarbons (CFCs, same molecular structure as methane but with chlorine and fluorine atoms replacing the hydrogen atoms). The changes induced in global atmospheric composition are highly significant in relative terms, even though these gases are far less abundant than CO_2.

CO_2 equivalence, CO_2e

Intensification of the greenhouse effect by anthropogenic emissions of the well-mixed greenhouse gases other than CO_2 is generally expressed in terms of a CO_2 equivalent global warming potential (GWP in Gt/year CO_2 equivalent), taking into account on the one hand the immediate power of the added GHG in intensifying the greenhouse effect, on the other hand its atmospheric residence time. Thus, for methane with atmospheric residence time of 12 years, much shorter than that of CO_2, the CO_2 equivalence on a 100-year time scale is less than its instantaneous effect of about 72, but still more than 20. On the other hand, for some gases (an extreme case: sulfur hexafluoride or SF6, used for electrical insulation, with an atmospheric residence time of 3,200 years), the CO_2 equivalence is much larger (22,000 for SF6) than the already large instantaneous equivalence. However, because annual anthropogenic emissions of these gases (methane, nitrous oxide, CFCs, etc.) remain much lower in tonnage than the tens of billions of tons of CO_2, the actual CO_2 emissions (mostly from fossil-fuel burning) remain the dominant term (77%) of anthropogenic intensification of the greenhouse effect, with methane coming second at 14%, nitrous oxide third at 8%.

The need for a strategy to ultimately reverse the *"global warming"* trend

Avoiding dangerous climate change requires not just stabilizing these emissions, it requires stabilizing and perhaps reducing the concentrations of CO_2 and other GHGs via *a sustainable and efficient way of reducing the emissions*.
Intensification of the greenhouse effect warms the surface by increasing the infrared radiation flux downward from the atmosphere. This modifies all the other energy exchanges between surface and atmosphere. Heat is required to evaporate water, and this latent heat of evaporation is released in the atmosphere when the water vapour condenses or freezes in mist or clouds. Warming of the surface changes the strength and geographical distribution of the flux of water from the surface to the atmosphere. The water that goes up must come down: *"global warming"* modifies the flux of water from the atmosphere back to the surface in the form of rain or snow. Then, freshwater runoffs and more generally freshwater availability on land also changes.

General conditions are expected to become drier in the sub-tropical zone, in parts of which subsistence agriculture is already at the limit of sustainability. This could lead to famine and very difficult waves of migration. The changes in the water cycle also involve increasing variability. Some prolonged droughts may occur more often. In other areas, even those with decreasing average precipitation and runoff, the risk of damaging floods is increasing, as for example along the Danube. In the Atlantic-Caribbean sector, the strongest tropical cyclones appear to be getting more frequent and more severe. There is also a risk of sudden abrupt climate shifts, radically changing the world map of agricultural productivity if *"global warming"* goes beyond some as yet poorly defined threshold.

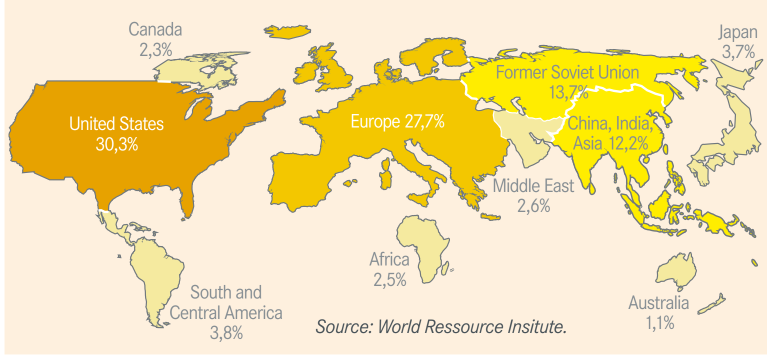
It is then important not to allow GHG emissions to continue to grow after the year 2030. With the long atmospheric residence time of CO_2 and some of the other GHGs, increased GHG concentrations will persist for many decades even after emissions are reduced. To keep the peak emissions level from growing much higher than the present level, industrially developed countries (North America, Europe, Japan), responsible for most of the increase up to now, should show the way and reduce emissions, and other countries move rapidly to limited GHG emissions. Until Earth's energy balance is stabilized, storage of excess heat in the oceans continues. It will return to the surface and produce further warming for centuries.

Climate versus weather?
Climate constitutes a statistical summary of the conditions near the surface, including mean values over periods of times ranging from days to years. For example, for Brussels, average July temperature in the period 1961-1990 (the "normal" for statistical climatologists) was 17.2°C, average July rainfall 75 mm. It is often said that "climate is what you expect; weather is what you get". Climate includes the damaging events that you had better prepare for even though you do not expect them often and hope never to see them. Mean values are not enough; a complete climatology must also include the likelihood of extreme values.
Thus, again for Brussels, there have been months of July with more than twice the "normal" rainfall, and others with less than 60 mm; and for some July days, maximum temperatures have been higher than 37°C. For the western coasts of Europe, major risks correspond to violent winter storms; for the southeast and Gulf coasts of the United States, the biggest risks come with tropical cyclones arriving between July and October. On coasts with high tidal amplitude, coincidence of spring-tide high water with a strong storm surge can be catastrophic, as around the North Sea on February 1, 1953. Inland, risks of flooding during periods of high rainfall differ by region and season. In Europe, major floods have occurred both in summer (as for example in 2002 in central Europe) and in winter (the "hundred-year" flood of January 1910 in Paris). Near the Mediterranean, local intense rainfall events cause damaging floods in autumn, as with the catastrophic Turia flood in Valencia (Spain) on 14 October 1957.

The need to invest in a new way of living and working

What are the principal sources of anthropogenic GHG emissions? How do lifestyles, like mobility, housing, comfort and food preferences compare? Energy and carbon intensities provide a measure of the problem, and a signal of what can contribute to the solution

Map of the world proportional to carbon dioxide emissions (1900-1999)

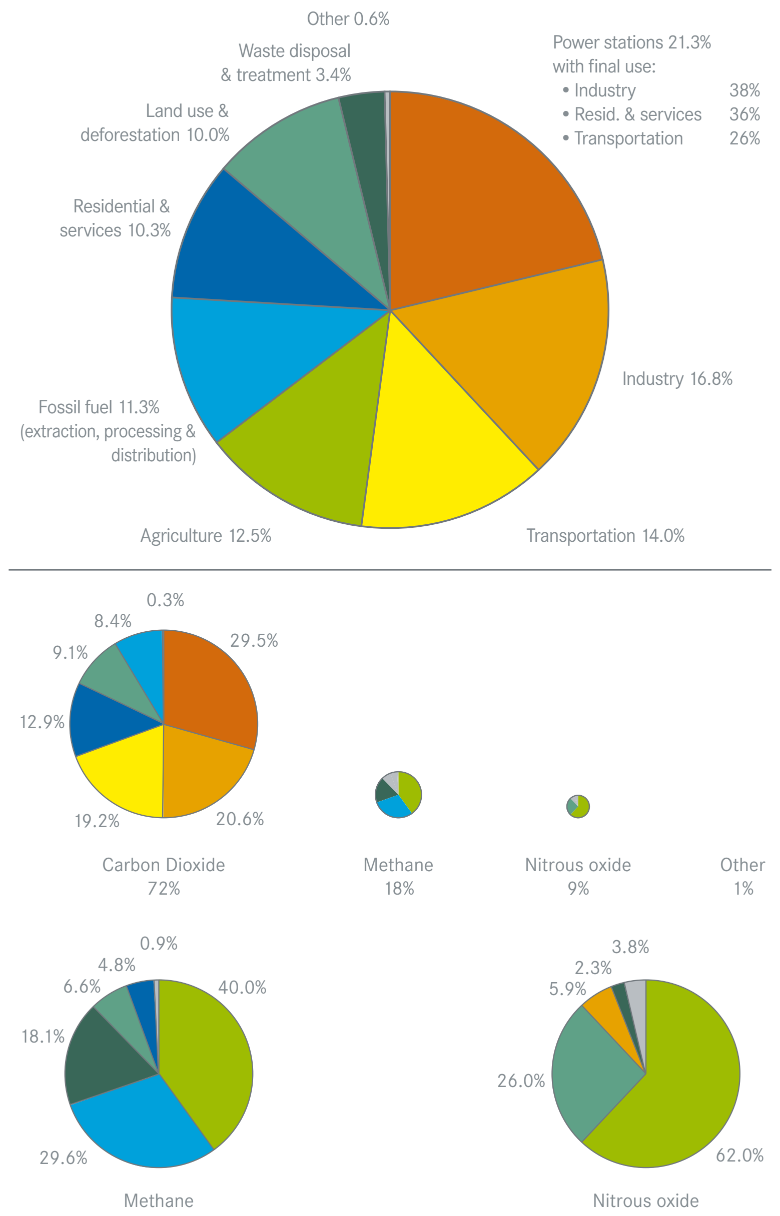


In terms of tonnage, CO_2 overwhelmingly dominates anthropogenic GHG emissions. In terms of greenhouse effect intensification on a 100-year basis, the driver of climate change, CO_2 emissions as such account for over 75% of the total global warming potential (GWP) effect expressed as CO_2-equivalence (CO_2e). Most of the CO_2 emissions come from burning fossil fuels. Coal and oil account for about 40% each, while natural gas accounts for the remaining 20%. Ample resources of coal exist, but burning coal releases more CO_2 per unit energy produced than the other fossil fuels. Liquid fuels derived from crude oil are extremely convenient, especially in transportation, but accessible resources are limited and we have to reduce our dependence on them. Considering the likely decline of production, the overall trend seems for oil prices to rise despite short-term fluctuations. The already rapidly increasing use of natural gas, a *"clean"* and convenient fuel, will likely increase still more over coming years.

While emissions of CO_2 from production of energy (burning fossil fuels) account for over 70% of all anthropogenic CO_2 emissions, land use change, in particular deforestation (now mostly in the tropical zone, partly compensated by some reforestation elsewhere, global net over 7 million hectares per year) leads to about 5 billion tons of CO_2 emissions per year.

The evolution of the geographical distribution of the CO_2 emissions reveals the responsibilities of the industrially advanced countries in producing the rise of CO_2 from 1750 to 2000. Consideration of the changes in the geographical distribution also reveals the role of population and economic growth (especially in China) in growth of GHG emissions since the year 2000.

Greenhouse gas emissions by sectors



Source: Emission Database for Global Atmospheric Research.

Considering sectors of activity, production of electric power is the growing dominant source of CO_2 emissions. Since the 1970s, CO_2 emissions have been dominated by electric power production, but emissions due to road transport have grown at a faster rate. Emissions by industry have not grown even though production of goods and services grew considerably during this period. However, production of electric power is no more an end in itself than is the production of GHG emissions. The important question is what the electric power is used for. Apportioning the electric power production by sector of end use, and considering all GHG emissions in terms of CO_2 equivalence, the striking result is the importance of agriculture as well as the sectors of transport, residential and commercial buildings, and manufacturing.

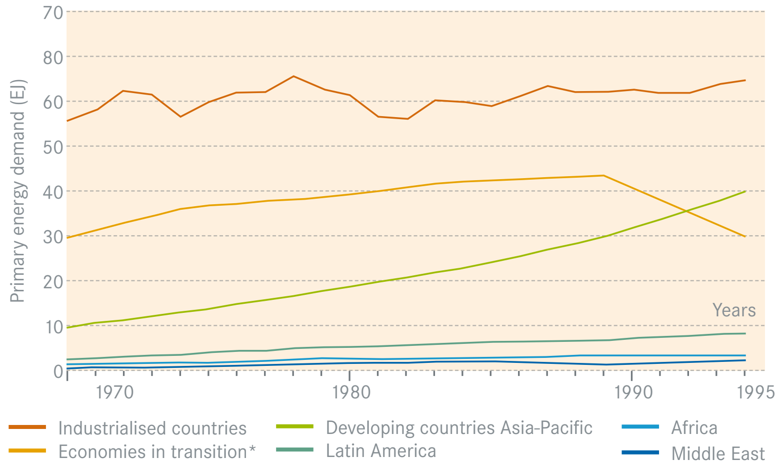
Emissions of other GHGs, expressed in CO_2 equivalence, are first of all mostly methane coming from agriculture (inundated rice paddies), livestock (cattle and other ruminants) and manure, as well as from other waste. After methane, the important contributor is nitrous oxide mainly due to the expansion of agriculture aided by chemical fertilizers, followed by a certain number of molecules (CFCs, HCFCs...) created and produced by the chemical industry to satisfy important needs. In this case, as in any others, the whole life cycle of the products must be analyzed. This will be further developed in this book.

Agriculture

Agriculture comes in with particular importance, with CO_2 emissions in a small part due to agricultural machinery, but much more from changes in land use as increasing populations clear and burn forest. As important are the methane emissions related to rice cultivation, livestock, and manure. Choice does come into play, although regarding rice consumption it is largely climate that determines where the cultivation of rice can better satisfy basic needs than growing wheat or corn. Choice comes more strongly into play where beef consumption is concerned, and more generally the choice of frequent consumption of meat is a significant factor in worldwide GHG emissions. This is because animals and fowl must be fed, and producing their feed requires greater use of land, water resources, fertilizer, and agricultural machinery, and because methane is generated in their waste.

With regard to agriculture, although practices used in intensive cultivation have played an important role in increasing food production to satisfy basic needs, such practices contribute to growing GHG emissions. Deep plowing may enhance CO_2 emissions by intensifying soil oxidation. Use of chemical nitrogen-based fertilizers has led to substantial increase in nitrous oxide emissions but also to net GHG reductions. It is not at all clear that essential food production can be ensured without such modern methods. However, their efficiency can benefit from more ingenuity, in the chemical industry as on the farm, taking into account the necessity of reducing GHG emissions. This is under way in Europe (EU-27), where agriculture-related methane and nitrous oxide emissions fell by about 20% between 1990 and 2006.

Evolution of industrial energy use



Manufacturing

Improvements in what is called energy efficiency have already been demonstrated in the manufacturing sector. Although primary energy use has grown steadily in the developing countries of Asia, energy consumption and GHG emissions have not followed the rise in production in the industrialized countries. Which is not to say that they – as well as the other industrialized countries - cannot do still better.

Residential and office building sector

Over 20% of anthropogenic CO_2 emissions come from the residential and office building sector, partly by way of fossil-fuel-generated electric power used for lighting, cooling, and some heating, partly by directly burning fossil fuels, mostly for heating. Heating is a vital necessity in cold climates, and air conditioning is an element of comfort enhancing the ability to work efficiently in hot climates.

Lifestyle plays a part in these emissions, an extreme example being the choice common in much of the United States to heat to temperatures above 23°C in winter while cooling below 18°C in summer. However, technological factors are at least as important. For new structures, appropriate architectural design can reduce the need for artificial lighting and air conditioning and enhance the possibility of passive solar heating during the cool season. For existing as well as new structures, improving thermal insulation is without any doubt the most important measure for reducing energy requirements and CO_2 emissions related to heating and cooling. Besides, new lighting technology can also strongly reduce electricity consumption.

Transport

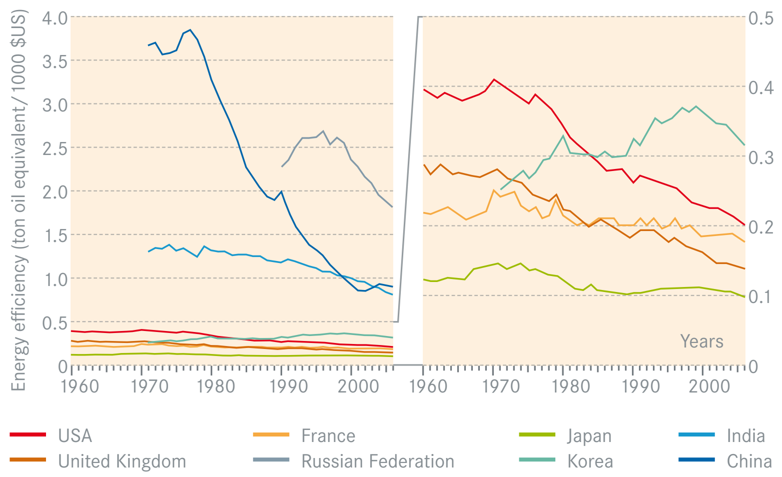
In the sector of road transport, with a strong rate of increase of CO_2 emissions worldwide, technology can be a part of the climate solution. Lifestyle mobility choices interact with factors of urban planning, and here as for habitat, the layout of cities and industrial parks cannot be changed instantaneously. For transport on water or in the air, increasing CO_2 emissions may not yet be a significant factor worldwide, but for the respect of national GHG emissions reduction targets, the question of identifying emissions over international waters with particular countries has not yet been resolved.

** Industrialized countries of the former Soviet bloc, in transition to a market economy.*
Source: IPCC3 - TAR - Figure 3-11.

Energy and carbon intensities

Although over past centuries, standard of living has tended to rise along with increased energy production, most of this accompanied by increased emissions of greenhouse gases, this correlation has tended to break down in the most technologically advanced countries.

Evolution of energy efficiency

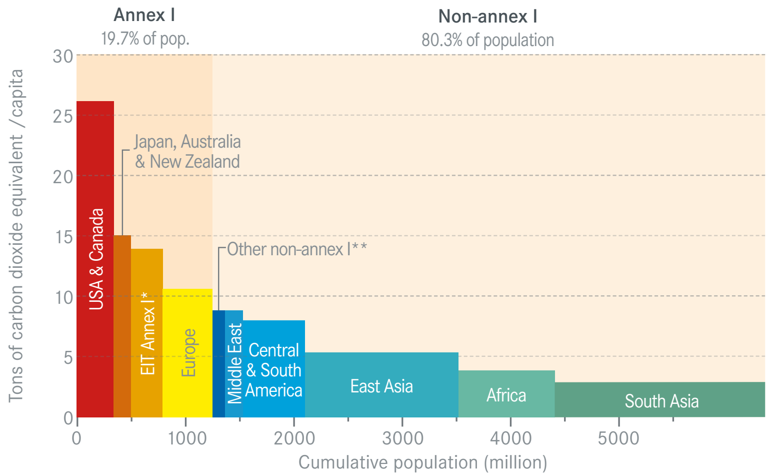


Because part of the upward infrared radiation from the surface is absorbed by atmospheric greenhouse gases (and clouds) and re-emitted downward, the surface is warmed to an average temperature of +15°C and emits 390 W/m² of infrared radiation upward to the atmosphere. Anthropogenic emissions of greenhouse gases intensify the natural greenhouse warming by increasing the proportion of infrared radiation re-emitted to the Earth's surface.

Source: World Resources Institute - OECD/IEA.

Where some arguments emphasize population, others emphasize per capita carbon emissions, and argue that the rich countries where these emissions are high must show the way in emissions reductions. Of course both terms are involved in determining world GHG emissions.

Regional distribution of greenhouse gas emissions by population



In this diagram, the heights of the colored rectangles correspond to per capita greenhouse gas emissions. The widths correspond to population. The area of each rectangle is the product of the two, and gives the total greenhouse gas emissions for that region.In annex I countries, the average greenhouse gas emission is 16.1 tons of carbon dioxide per capita. It is 4.2 tons in non-annex I countries.

** **EIT annex I:** corresponds to Economies In Transition countries, i.e. former members of the Soviet bloc, having signed on to emissions abatement targets in the Kyoto protocol. Some of these countries have become members of the EU.*

*** **Other non-annex I:** Albania, Armenia, Azerbaijan, Bosnia Herzegovina, Cyprus, Gemorgia, Kazakhstan, Kyrgyzstan, Malta, Moldova, San Marino, Serbia, Tajikistan, Turkmenistan, Uzbekistan, Republic of Macedonia.*

Source: IPCC AR4 Synthesis Report - Figure 2-2.

Population is only part of the story. As important is the matter of standard of living. Economists have usually measured wealth production in terms of gross domestic product (GDP), expressed in dollars (appropriately adjusted for purchasing power). Taking this per capita wealth production as a measure of standard of living, one can relate this to the energy production per capita using the energy intensity in kilowatt-hours per dollar (kWh/$), and to CO_2 equivalent GHG emissions per capita using the carbon intensity of wealth production ($tCO_2e/\$$). One can also express the carbon intensity of energy production (tCO_2e/kWh). Large values of energy or carbon intensities correspond to poor efficiency in producing wealth. For the world as a whole, annual GHG emissions (tCO_2e/yr) are obtained by multiplying the terms of what is called the Kaya equation (attributed to Professor Kaya of Japan).

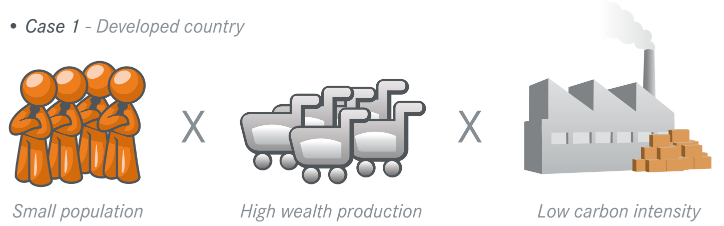
The Kaya equation
GHG emissions (tCO_2e/yr) =
Population
- *per capita wealth production ($/yr)*
- *energy intensity of wealth production (kWh/$)*
- *carbon intensity of energy production (tCO_2e/kWh)*

or alternatively
GHG emissions (tCO_2e/yr) =
Population
- *per capita wealth production ($/yr)*
- *carbon intensity of wealth production ($tCO_2e/\$$)*

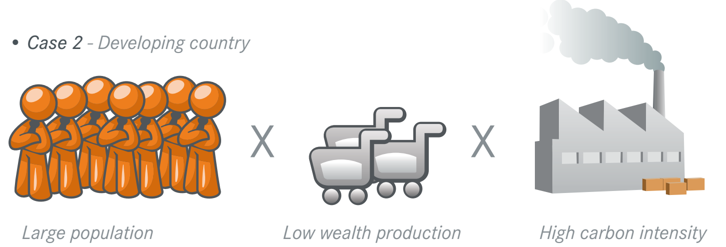
For the climate change problem, the carbon and energy intensities must be considered along with population and standard of living. One can imagine a situation in which the use of renewable energy sources (including biofuels), together with nuclear-generated electric power, strongly reduces anthropogenic CO_2 emissions. Some studies indicate however that expanded production of biofuels may lead to strong increase in CO_2 emissions from the land-use changes involved. In any event, energy intensity matters, in the sense that producing wealth with less use of energy and less use of non-renewable resources and limited space is generally to be preferred to waste of energy and space. In the near term, non-renewable resources will however continue to play an important role in chemistry.

According to the Kaya equation, similar greenhouse gas emissions can be obtained for:

- *Case 1 - Developed country*



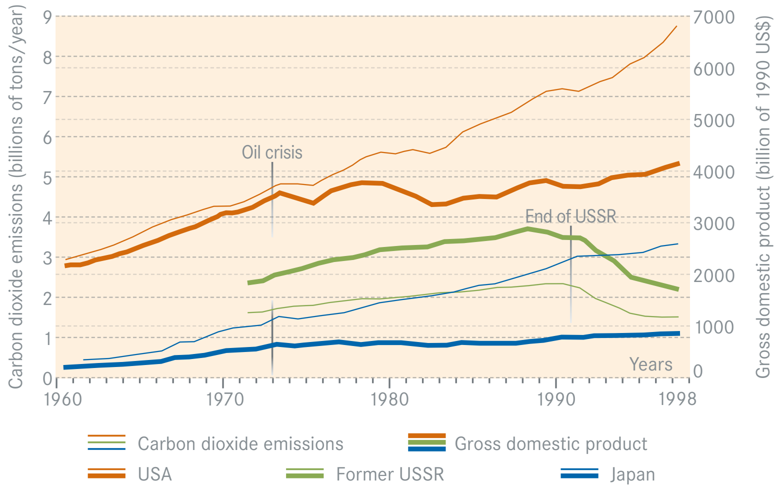
- *Case 2 - Developing country*



The problem. How can the growing world energy demand, driven by the aspiration to a better standard of living as well as by population growth, be balanced against the need to reduce GHG emissions?

Both population growth and economic growth have driven world energy demand, but, once development and standard of living have reached a certain level, efficiency of energy use in producing wealth has improved, and energy and carbon intensities have generally declined with time. One exception has been the former Soviet Union, where energy and carbon intensities (*i.e.* inefficiencies) were high in 1990 and did not drop more quickly than GDP in these *"economies in transition"*.

Comparison between economic growth and carbon dioxide emissions



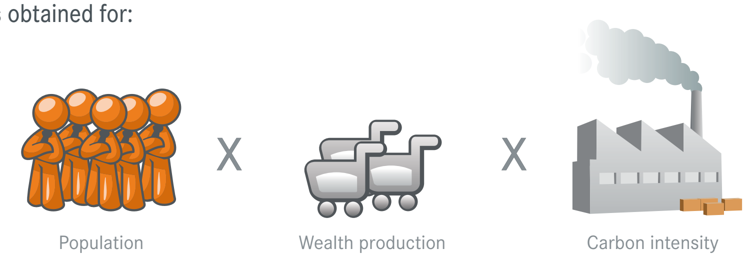
Note that for former USSR, greenhouse gas emissions have fallen, essentially as a result of economic collapse rather than as a result of any incipient improvements in efficiency as they make the transition to a market economy.

Source: IPCC4 - SYR - Figure 5-6

The growth of world population, and the legitimate aspiration to escape still all-to-prevalent poverty, would seem to imply a continued growth of world energy demand and corresponding growth of GHG emissions. The per capita GHG emissions still are much smaller in China and India than they are in Europe or North America, even if the weight of these countries in total GHG emissions has become strong and is increasing very quickly. The driver is economic growth rather than population growth where China is concerned, both population and economic growth for India and other countries.

Standard of living can however be improved without increasing GHG emissions by the same factor. This can be seen by examining the different terms in the Kaya equation and in particular the carbon intensities in different countries.

According to the Kaya equation, high greenhouse gas emissions is obtained for:



Improved the standard of living with similar, or reduced, greenhouse gas emissions is obtained by significantly reducing carbon intensity:

Per capita emissions are extremely low in Africa, as is per capita wealth, but carbon intensity is very high there, meaning that the population as a whole is getting far less benefit than Americans or Europeans for each ton of CO_2 emitted to the atmosphere, as for each ton of fuel consumed. More generally, carbon intensity is high, *i.e.* efficiency is low, in the less developed countries and in the former Soviet bloc. If, by a combination of technology transfer, fair protection of related intellectual property rights and improved efficiency, carbon intensity there is brought down to the present level of Western Europe and Japan, production of wealth can be twice as much for a given level of GHG emissions. For North America, carbon intensity is close to the world average, very high considering the advanced state of technology in the US and Canada, and here again there is a potential – recognized by the US administration - for significant reduction of GHG emissions without reduction of wealth production – on the contrary.

Getting there will not be easy. In the developing world, the necessity of sustaining growing urban populations with food and other basic needs drives the growth in needs for transportation as well as for more productive agriculture. In the developed world, lifestyle interacts with existing infrastructure for electric power production and transmission, as well as urban structure and transportation.

Some of the carbon intensity differences by country appear in the carbon intensities specific to the chemical industry, *i.e.* the values of $kgCO_2e$ per US dollar sales of the industry. For China and Eastern Europe, chemical industry carbon intensity was larger than 2 $kgCO_2e$/$ in 2005; for Switzerland it was only 0.05, thanks to the dominance of hydroelectric and nuclear power. For Western Europe, carbon intensity was 0.41, for the US 0.70 $kgCO_2e$/$, the global average being 0.81. There is then room for improvement.

An example of implemented solutions? The chemical industry's commitments to reduce its emissions in the atmosphere and environmental side effects

In contrast to impressions one may get from some media and activist discourse, the chemical industry has demonstrated a capability of rapid response to environmental concerns and requests for sustainable development, once these come to light. The case of the chlorofluorocarbons (CFCs) is particularly illuminating in this respect. When the chemical industry invented and developed CFCs beginning in the 1930s, these constituted an enormous progress, providing new fluids for use in refrigeration and cooling circuits, much safer, less likely to provoke panic in case of leaks, and easier to use than fluids such as ammonia used till then. Refrigeration after all is vital for safe preservation of food.

It was only in the 1970s that scientists began to realize that the principal advantage of the CFCs, their chemical inertness and relative indestructibility, led to their persistence and accumulation in the natural environment. When these gases finally reached the stratosphere (from 10 to 50 km altitude), they dramatically increased destruction of ozone by way of catalytic reactions. Stratospheric ozone plays the vital role of shielding the Earth's surface from the solar ultraviolet radiation that tends to disrupt the structures of the complex molecules of life, causing certain cancers and cataracts. Discovery of the Antarctic *"ozone hole"* and the heightened concern it raised led to adoption of the 1987 Montreal Protocol and the phase-out of CFC production. This was possible only because the chemical industry had rapidly developed appropriate replacements for use in cooling systems, gases which when released into the atmosphere tend to be destroyed before they can accumulate in the stratosphere.

This industry showed comparable efforts in contributing to development of *"scrubbers"* to remove sulfur dioxide – dangerous to health and by way of acid rains to the environment - from the gases released by thermal power plants and factories using high-sulfur coal or oil. Application of such devices has already dramatically reduced sulfur dioxide emissions in Europe and North America, at low direct economic cost and with significant benefits in air and water quality. One may also note industry's development of catalytic converters eliminating gases dangerous to health from motor vehicle effluents.

It remains to be seen to what extent the chemical industry can contribute to the development of technologies to trap large quantities (at least hundreds of millions of tons per year) of CO_2 - the dominant waste product of fossil fuel combustion – in what is called carbon *"sequestration"* or CCS for carbon dioxide capture and storage. It also remains to be seen to what extent such a technology will make sense from an ecological and economical point of view, compared to other options.

Climate change and chemistry: Finding innovative solutions in everyday life

52 Chemistry in the light of climate change: part of the common solution as well as part of the common issue

- Like any emitter on earth, the chemical industry is part of the issue
- The chemical industry is an energy-intensive industry
- It uses fossil fuels as raw materials
- As part of society, it is under pressure to reduce its carbon footprint
- The chemical industry is part of the solution
- It has improved the efficiency of its operations
- It has recycling possibilities
- It offers CO_2 savings through its products
- Thermal Insulation
- Farming
- Lighting
- Renewables
- Mobility
- Other products enabling GHG emissions abatement
- Mitigation of Climate Change requires a strong and innovative European Chemical Industry

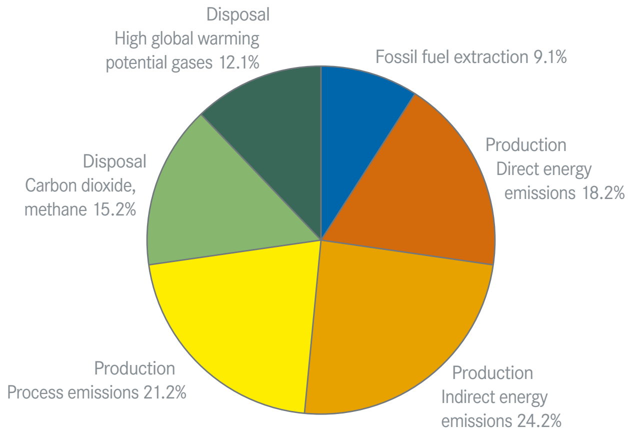
74 The chemical industry currently provides the tools and the foundation for a sustainable future

- It provides direct and enabling solutions to reduce global GHG emissions
- It develops tools to reduce emissions and to capture them
- It develops tools to reduce emissions of carbon dioxide in everyday life
- It develops technologies for more effective use of renewable energy resources
- It creates new materials while preserving the existing stocks of raw materials

Chemistry is part of nature, but humanity has further developed chemistry, beginning very crudely with the combustion of wood and fossil fuels to produce heat and energy. Humanity has developed chemical industry, with far more sophisticated processes and products. Until the last half of the 20th century, humanity seems to have proceeded on the assumption that the world's atmosphere, oceans and soils can take care of industrial, agricultural and other waste products, by-products, pollutants...

Beginning with the industrial revolution, rapidly increasing exploitation of energy and other resources made possible a dramatic increase in human numbers and human wealth. This way of exploiting resources and releasing waste is no longer sustainable in a finite world. Although it is an energy-intensive industry, the chemical industry has an important role in that its end products often have energy-saving and environmentally friendly properties. The contribution of chemical products to the reduction of GHG emissions must be seen in the context of their decisive power to reduce emissions in all areas of economy and society.

Total lifecycle emissions of chemical industry products (2005)



Total greenhouse gas emissions of the chemical industry was 3,300 million tons of carbon dioxide equivalent in 2005. This figure does not include emissions savings enabled by products of the chemical industry.

Source: ICCA Report

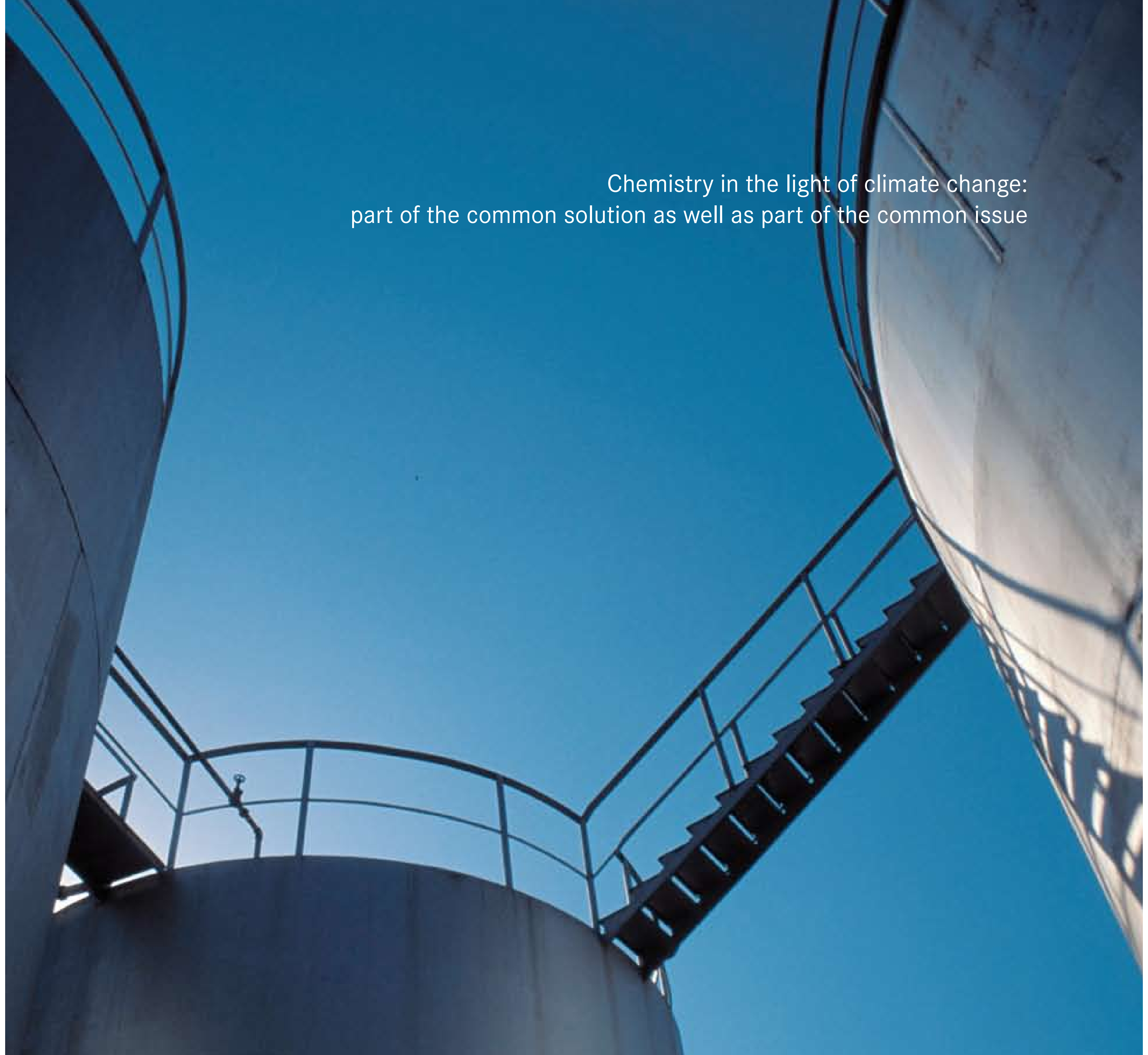
Like any emitter on earth, the chemical industry is part of the climate change issue

The chemical industry is an energy-intensive industry

The chemical industry necessarily uses energy in its activities. The ICCA report (Innovations for greenhouse gas reductions, 2009) evaluates its total production-related GHG emissions at 2.1 $GtCO_2e$ in 2005, a significant fraction of the total global anthropogenic emissions. Two-thirds of the production-related emissions come from energy use. There are direct emissions of CO_2 when coal, oil or natural gas is burned to maintain the process. There also are indirect emissions of CO_2 from power plants that burn such fuels to provide electricity used by chemical industry. The total of these energy-related CO_2 emissions comes to over 1.4 billion tons (=Gt) of CO_2 per year, over 5% of global energy-related CO_2 emissions.

One must also add a fraction of the methane emissions from leaks that occur in the coal-mining and oil-drilling operations supplying the fuel for the chemical industry's energy needs. The carbon intensity of the total energy-related emissions ranges from high values of about one ton CO_2 equivalent per thousand kilowatt-hours (1 tCO_2e/MWh) for China, India, and Russia, to values as low as 0.09 tCO_2e/MWh in Brazil (powered by renewable sugar-cane-based ethanol) and France (nuclear- and hydro-powered). Intermediate values (0.5-0.7 tCO_2e/MWh) obtained in the US, Japan, and Western Europe.

Chemistry in the light of climate change: part of the common solution as well as part of the common issue



The chemical industry uses fossil fuels not only as energy sources, producing CO_2 emissions, but also as raw materials for the manufacture of sophisticated products, some of which also emit GHG when incinerated at the end of their lifetime. During their whole life cycles there are products that earn their emissions back; some of them earn significantly more than emitted

Although in some sense the chemical industry is energy-intensive, it is even more ingenuity-intensive. It uses energy to transform the relatively simple molecules of hydrocarbons such as petroleum into much more elaborate molecular assemblages with more valuable applications than just burning them. Although GHG emissions as such have not so far entered into price considerations for the final consumer, many chemical industry products have found consumers because they lead to large and competitive energy savings.

Total process-related emissions represent 0,67 $GtCO_2e$ in 2005. In addition to GHG emissions (mostly CO_2) coming from its energy use, emissions of CO_2 and other GHGs, especially some with high global warming potential (GWP) occur as part of its production processes. As an extreme example, although only 515 thousand tons of HCFC-22 were produced in 2005, the associated emission of powerful GHGs came to 0,07 $GtCO_2$ equivalent.

The raw material most commonly used by the chemical industry is still petroleum at least in Europe. Again, one must count in the industry's GHG emissions some fraction of the methane leaks in the extraction. Apart from this, oil thus used as raw materials by the chemical industry to make the more elaborate molecules that go into its many useful products do not directly emit greenhouse gases, in contrast to the inevitable production of CO_2 and H_2O when hydrocarbons are simply burned.

However, one must include the full life cycle of the chemical industry's products in evaluating the GHG emissions. A critical question is what happens at the end of lifetime of these products. As plastics are in essence solidified oil, when used for power and/or heat generation, they generate emissions of (mostly) CO_2, estimated at 0.5 $GtCO_2e$ in 2005. At the same time these plastics can replace the oil resource that would otherwise be burned and so offset some or all emissions depending on the technology used. The range goes from moderate additional CO_2 emissions in incinerators to significant savings when used with high efficiency energy recovery. Thus in fact plastics can extend the life cycle of oil. Alternatively the lifecycle of plastics/oil can be extended by recycling resulting in similar CO_2 emission savings. Sustainable recycling however depends very much on quality of the waste stream and the related costs of recovery.

What happens to the relatively small quantities of the most powerful greenhouse gases is at least as important. Although production of CFCs has ended, some CFCs continue to escape into the atmosphere from discarded refrigerators, air conditioners and other such equipment. This prolongs the period of stratospheric ozone depletion, and also adds to the greenhouse effect. It would be better (and in some cases is legally required) to recover them and not allow such escape into the atmosphere, possibly reusing these remarkable products if not destroying them. The fact, however, is that the escape of such gases into the atmosphere added 0.4 $GtCO_2e$ to GHG emissions in 2005. This is an example of the improvements that the chemical industry is able to implement when asked by science and consumers. The waste management industry has also its role to play in that matter.

Of course, production and disposal of chemical industry products leads to GHG emissions. At the same time, these products play essential roles in maintaining modern life, health, safety, and in many cases they reduce the use of energy and the emission of GHGs in other sectors of human endeavor. Very often, these reductions more than compensate for the GHG emissions incurred in the chemical industry's processes. Using a full life cycle analysis, the ICCA report tries to quantify the savings.

As part of society, the chemical industry is under pressure to reduce its carbon footprint in cooperation with all its consumers

All human activities have a carbon *"footprint"*, *i.e.* they involve net emission to the atmosphere of carbon dioxide and other GHGs, intensifying the greenhouse effect. Before the 1990s, consumer choices never explicitly took into account the carbon footprint of a product, although at least for those for which energy input is high and a factor in cost, the carbon footprint affects the price paid. Over the last 10 years, society has become aware of the dangers of climate change, and so there is increasing pressure to reduce the carbon footprint of its activities. For the industry, one must consider the whole life cycle of a product to identify those that earn their emissions back, and one can do more to inform downstream users and consumers of such lightening of the carbon footprint.

The chemical industry must also identify those processes and products that can be significantly improved so as to abate overall GHG emissions. This is already under way with regard to the process-related emissions of powerful (high-GWP) greenhouse gases. As an example, the European chemical industry increasingly uses catalysts or other tools such as filters to eliminate nitrous oxide emissions from production processes. Between 1990 and 2000, European (EU-27) industrial process emissions of nitrous oxide were cut in half.

The chemical industry is part of the climate solution

The chemical industry has improved the efficiency of its own operations

As in other industrial sectors, and to a large extent as a result of the increasing price of energy since 1970, the chemical industry in market economies has strongly improved its energy efficiency. In the European Union, chemical industry output increased by 60% while energy consumption remained constant and GHG emissions fell by nearly 30%, corresponding to strong reductions in energy and carbon intensity.

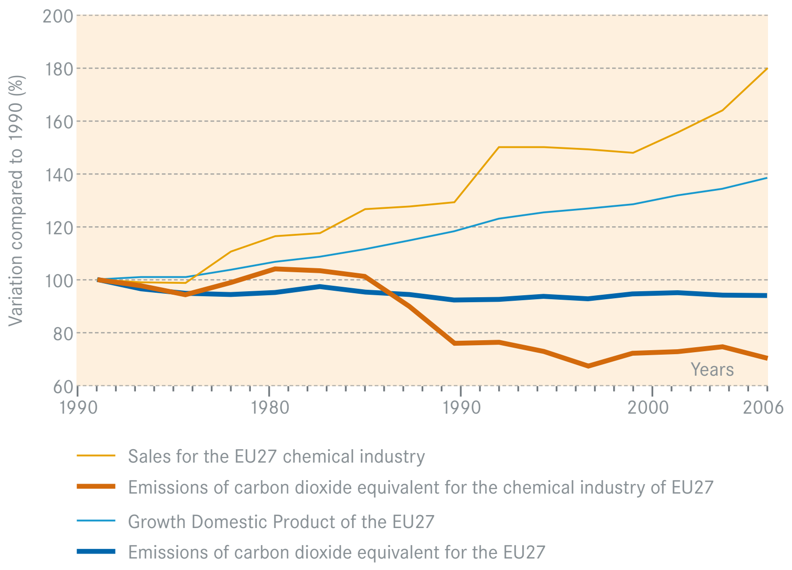
In the United States, chemical industry energy consumption per unit output decreased by nearly 50% from 1974 to 2005; its GHG emissions fell by 13% from 1990 to 2005. In the emerging economy of Brazil, the chemical industry increased production by 30% between 2001 and 2007 while reducing energy consumption (half from renewable sources) by 25%.

Such improvement in energy efficiency is a necessary reaction to the general trend of rising energy prices, independent of explicit concern for reducing carbon footprint. Continuation of this trend, interacting with international and national governmental measures, (carbon emissions regulations and trading) aimed at reducing carbon footprint, will reinforce the incentive for efficiency improvement. Support for research and development must be maintained if the chemical industry is to continue to reduce its carbon footprint and dependence on fossil resources.

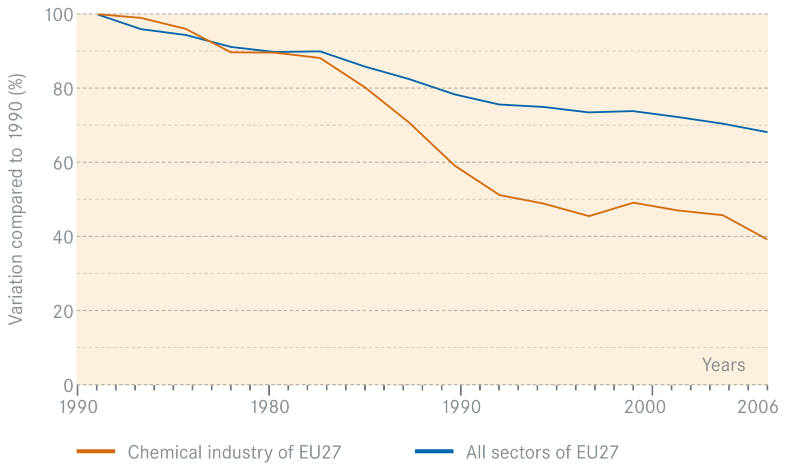
The chemical industry has the ability to recycle to help deliver the low carbon society

Many products made from chemicals may raise environmental issues because of their slow degradability, indeed – apart from incineration - their stability. This issue is also a matter of lifestyle and of lack of incentive for appropriate disposal and recycling, in particular for packaging and other plastic products. By the same token, however, a large range of these slowly degrading materials could be candidates for recycling. With appropriate recovery and recycling systems, these products could continue to render service. The possibilities are there, and with them opportunities for new added-value activities of low carbon footprint. At the same time, recycling slows down the rise of demand for feedstocks such as petroleum, whose prices are likely to rise.

Comparison of evolution of economic growth and carbon dioxide emissions



Evolution of carbon intensity for EU27 and chemical industry of EU27

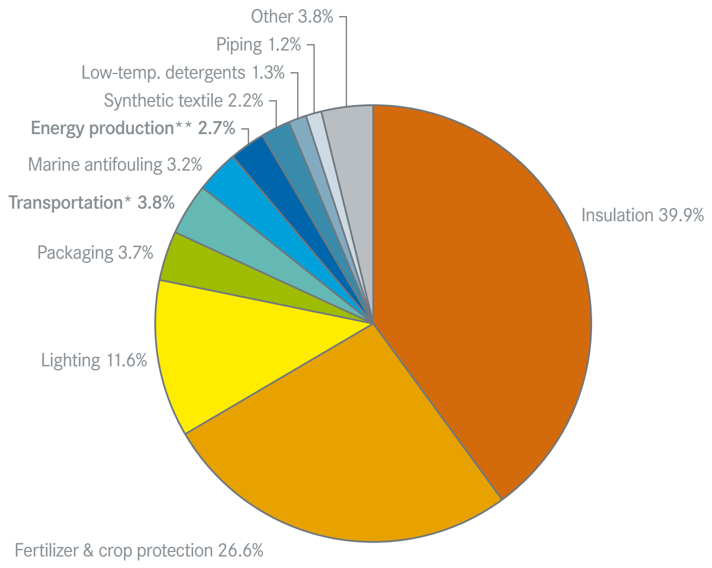


Sources: European Environment Agency and Eurostat

Waste management: recycling or incineration?
What do European industries propose under the "eco-efficiency" projects?
Many products from the chemical industry, where they are not being modified by their use, could be recycled back into their original products. In practice, only a limited fraction of chemical industry products are as yet recycled. For plastics overall recycling is at the level of 20%, because only clean unmixed plastics wastes can be easily recycled at reasonable cost. Products not suitable for recycling, in particular soiled and mixed waste streams, are well suited for energy recovery technologies such as cement kiln or modern co-combustion. As noted for example in the Prognos report on waste management in Europe, the best way to improve the environmental performance of end-of-life plastics is to divert them from landfill and to completely recover them, either by recycling or by energy recovery. Some EU27 states are already at 49% plastics wasterecovery (recycling + incineration) but many "land-filling" states are only at 24%. This and other studies also made clear that recycling may have some limited potential: more recycling can lead to higher costs and barely improved environmental performance. At the beginning of this millennium this optimum for packaging waste was calculated at 15%, today we are at 29% for the EU27 + Norway and Switzerland. This figure could increase, but this will take time. Further improvements towards sustainable end-of-life management will be a combination of recycling and energy recovery.

***Reference:** Prognos report. Resource saving and CO_2 reduction potential in waste management in Europe and the possible contribution to the CO_2 reduction target in 2020. Berlin, 2008.*

Chemical industry applications and the net abatement (final product savings in industry emissions) they allowed in 2005



Most important, the chemical industry is positioned to offer CO_2 savings through its downstream products

For any industrial product, evaluation of CO_2 and other GHG emissions savings enabled by such products requires a full life cycle analysis, from production through use over the product lifetime, to final disposal, making also a comparison with the life cycle emissions of possible or actual alternative products providing the same services.

At present, the most important areas of emissions savings enabled by chemical industry products are thermal insulation, farming, lighting, transport, packaging, textiles, and other consumer goods.

Total net greenhouse gas emissions abatment allowed by chemical industry application was 6,010 million tons of carbon dioxide equivalent in 2005 (including fertilizer and crop protection). Without agriculture, the abatment is 4,000 million tons.These figures alos includes 850 million tons of carbon dioxide equivalent for which no realistic non-chemical alternative exist.
** **Transportation:** automotive weight reduction (120 $MtCO_2e$), improved engine efficiency (70 $MtCO_2e$) and green tyre (40 $MtCO_2e$).*
*** **Energy production:** wind power (60 $MtCO_2e$), solar power (40 $MtCO_2e$) and district heating (60$MtCO_2e$).*

Source: ICCA Report.

Life Cycle Analyses. What they are. How they can be useful

As noted, the chemical industry is energy-intensive, and a life-cycle analysis (LCA) of its operations takes into account first of all these greenhouse gas emissions in production, including GHG emissions related to energy use, which depend on the fuels used indirectly to produce electricity as well as directly for heating in the production process. It also takes into account the non-energy GHG emissions in the chemical process itself. For purposes of comparison, the same calculations are made for the "non-chemical" alternatives, when they exist, such as metals.

The LCA analysis also includes what happens at end of life of the product, whether it is incinerated producing GHG emissions whether or not the heat is wasted, whether it is recycled, or whether it simply ends up in landfill. There are mitigation possibilities in these phases, but even more important, one must consider GHG emissions savings made possible by chemical industry products replacing "non-chemical" alternatives where such alternatives exist.

In this respect, the most important part of the LCA is to take into account what happens during the life of the product. Thermal insulation in particular pays for itself over a small fraction of its lifetime by reducing energy needs for heating or cooling, and because in most cases GHG emissions come along with the energy production. Up to now, paying for itself has been essentially in terms of less money spent over product lifetime for electricity and fuel. The LCA computes the associated GHG emissions abatement and compares them with the alternative – mineral wool in the case of roof insulation. Similarly, the LCA yields an overall GHG emissions abatement for compact fluorescent lamps replacing conventional incandescent lighting. These calculations use industry and expert figures concerning efficiency, fuel mix, lifetime etc

Thermal Insulation

Chemical industry products for building insulation are the most important factor in reducing energy consumption and CO_2 emissions in the course of modern life. This is true today and will very likely continue to dominate carbon savings in the future. Wherever year-round or winter temperatures go below 8°C, and this includes much of the industrially advanced countries of North America, Europe and Asia, indoor heating is essential for survival. Moreover, although habits vary in different populations, comfort and work efficiency require heating when outdoor temperatures fall below 15°C. Wherever year-round or summer temperatures go above 33°C, comfort and work efficiency require insulation and air conditioning. This again includes many of the industrially advanced countries (especially the U.S.A. and Japan, and parts of Europe) as well as the countries (India, China, Brazil...) with rapidly growing economies. Apart from buildings, insulation is essential for refrigeration equipment, vital for safe storage of perishable food.

Both for heating or cooling, whenever strong differences between outdoor and indoor temperatures must be maintained, energy is required, and in most cases that energy is supplied directly or indirectly (by way of electricity) by burning coal, oil, or natural gas, generating emissions of CO_2. Of course cultural habits and lifestyle govern in part the desired indoor temperatures, and architectural design and building size per person affect the heating/cooling requirements to maintain them. Still, building insulation is probably the major factor in limiting energy requirements for indoor heating or cooling. Moreover, considering that many at present poorly insulated buildings still have a long life (over 50 years) ahead of them, the only way to reduce their energy/carbon requirements while improving comfort is to improve their insulation. The added insulation can serve for 50 years and pay for itself in a much shorter time. In some areas (especially in the less developed countries), theoretically renewable wood is used for heating and cooking, but increasing exploitation of wood in fact generates net CO_2 emissions because of deforestation.

Building insulation significantly reduces heat lost by buildings. This appears clearly in night time aerial infrared (heat radiation) photographs, which immediately reveal those buildings with poor roof insulation. Wall insulation also limits heat loss in cold weather, and lack of adequate insulation on an outside wall of a house can easily be detected by touching the inside. Overall, the chemical industry produces much of the building insulation materials used in the world (the main non-chemical alternative being mineral wool, frequently used for roof insulation, but less for wall insulation because of its high volume). The insulation materials produced by the chemical industry are attractive because of their compactness and their efficacy.

Manufacture of insulation materials entails GHG emissions, both by way of energy consumption and in the course of production processes. However, over the lifetime of the insulation, the energy savings and the associated CO_2 emissions savings can amount to over **230 times** these emissions. The ICCA report calculates that building insulation supplied by the chemical industry made possible a net CO_2 emissions abatement of 2.4 $GtCO_2e$ for 2005. Savings were roughly equal in Asia, Europe, and North America. This comes to about as much as residential and commercial buildings contribute to those emissions. Without the insulation products, GHG emissions and heating bills attributable to buildings would be doubled.

In addition to making it possible to heat or cool buildings economically, insulation is essential in heating conduits in buildings and especially for those used in district heating systems. For a 4-megawatt district heating system using 45% plastics in piping, and assuming two-thirds fossil-fuel input (as opposed to wood and waste), the estimated reduction of overall heat input is 1%, and for 2,400 such systems this gives an emissions reduction of 55 $MtCO_2$ equivalent per year. The use of plastics and foam insulation remains attractive even if no fossil fuels are used to produce heat, because they reduce the demand on wood and wooded land, which is truly renewable only if it is not exploited too rapidly.

The ICCA study focuses on solutions enabled by chemistry vs. alternative solutions, and relies on comparative life-cycle assessments that produce figures about abatement solutions enabled by this industry. But the overall picture of chemistry's contribution to energy efficiency must also consider a wide range of other products and applications for which no alternative currently exists at industrial scale. At present, the downstream use would simply not exist. To take just one example, every ton of glass requires 20% of sodium carbonate as raw material at the production step. Over the lifetime of a window, this chemical thus significantly contributes to comfort and energy efficiency. In many similar cases, for many chemicals, especially basic chemicals that have been used for a long time as building blocks for other sectors, there is simply no basis to compare savings with alternative solutions.

Farming

Agriculture accounts for about 9% of global GHG emissions, half of it in the form of nitrous oxide mostly released from the soil. GHGs released by soils are generated by microbes living on the organic matter in soils and manures, and are the by-products of their natural activity. GHGs are emitted from the nitrogen in soil organic matter and manure as a result of microbial transformations of mineral nitrogen when it has been applied to the soil. Such transformations are natural and essential, but can be minimized by the optimization of nitrogen use efficiency by adhering to good fertilization practices. Thus chemical industry products for agriculture contribute only partly to the emission problem. Agriculture, however feeds the world's growing population which will reach 9 billion by 2050, and strong arguments can be made that the chemical industry products – especially fertilizer assisted by crop protection (pesticides) – have been essential in increasing agricultural yields to keep up with population growth and improve basic nutrition and, as importantly, limit the otherwise necessary land use change.

Without modern and highly productive agriculture using these chemical industry products, feeding the growing population in many parts of the world will require increasing even more the land surface devoted to food production, expanding cultivation to lands with marginal soils and water supply, or invading grassland and clearing forests. It would lead to the removal of growing trees and strong increased oxidation of managed soils which act as carbon sinks, resulting in new CO_2 sources, with a net increase in CO_2 emissions.

So-called *"organic"* farming, *i.e.* farming with application of minimal or zero chemical fertilizers and pesticides, and sometimes with minimal working of the soil, has become popular in some circles. This may reduce CO_2 and nitrous oxide and other GHG emissions per cultivated hectare.

The question is whether yield is equivalent or not. The ICCA study cites yield drops ranging from 30 to 85%, and adopts an average of 50%. Comparing GHG emissions associated with modern *"conventional"* chemically assisted farming, and a hypothetical world in which the same total agricultural production would be achieved without chemical aids, the ICCA study estimates that chemical industry products for agriculture provide a *net* GHG emissions abatement of 1.6 $GtCO_2e$ per year mainly due to avoided land-use change. The use of fertilizers and other agri-chemicals increases the efficiency of biomass production for energy by more than sixfold thus releasing the pressure to convert forests to arable land.

In Europe (EU-27), abandonment of marginal lands in favor of more intensive chemically-assisted farming has led to expansion of forest and increased uptake of atmospheric CO_2. At the same time, rather than increasing, nitrous oxide emissions fell by nearly 30% between 1990 and 2006.

Comparison of *"organic"* and *"conventional"* farming remains subject to debate. Besides, comparable yield gain could be obtained with more appropriate use of the chemical products, and this would reduce costs of downstream water purification. In that respect, European agriculture today is reported to produce more crops with less nitrogen fertilizer than 20 years ago. Sustainability of the yield gain in chemically assisted modern intensive agriculture without adequate management of needed products can remain arguable, as can the question of ecological effects of chemical crop protection.

Another point: to what extent will expansion of land used for cultivation of biofuels be at the expense of land used for food production, managed forests, and unmanaged forests. Such changes could lead to strong increases of soil GHG emissions, negating part or all of the carbon advantages of *"renewable biofuels"* that could lead to the disappearance of *"natural"* forests. To what extent this will happen depends in part on possible chemical industry contributions to increasing yield in food and biofuel production.

Lighting

Lighting is the third most important area of GHG emissions abatement made possible by chemical industry products. These have already led to significant reductions in energy consumption. Lifestyle factors do play some role, for example whether or not people turn off the light when they leave a room, how much street lighting is desired and for how long, in some areas such as hallways, stairs or parking lots lights are left on permanently or turned on by motion sensors.

However, lighting technology makes the biggest difference, and the chemical industry contribution is essential. The most significant progress of the last ten years has been the development of compact fluorescent lamps (CFL) and their increasing use in homes, factories and offices. To produce the same desired illumination as conventional incandescent light bulbs, CFLs consume only a fourth of the electricity and so reduce by 75% the CO_2 emissions where fossil fuels are the source of electric power. High-quality CFLs also have a much longer lifetime than incandescent bulbs. Over an average lifetime of 7,000 hours (over 4 years at 4 hours per day), a CFL may save over 400 kilowatt-hours, thus reducing the consumers' electricity bill. Market penetration has increased with annual production (in 2005) of 2.82 billion bulbs, of which 47% are sold in the US, 34% in the EU and Japan, and 19% in the rest of the world.

Using an average emissions abatement of 590 kgCO_2e per thousand kilowatt-hours of electric power consumed, those 2.82 billion CFLs save 0,7 GtCO_2e over their lifetime. Even though light-inefficient incandescent bulbs contribute to heating, they do not do so in the best locations, and in the hot season they continue to heat and so increase air-conditioning power needs and associated GHG emissions. The CFLs, whose manufacture depends on chemical industry products, are a large step in the production of necessary illumination with a minimum of energy consumption and CO_2 emissions.

Renewables

The potential of renewable energy for global GHG emissions savings is enormous, but at present (especially for non-hydraulic energy resources) is far from being realized. In Brazil, the chemical industry as well as most automobiles use ethanol derived from renewable sugar cane. In Europe and other industrialized countries, some of the electric power consumed by industry comes from nuclear or hydroelectric installations. Regional circumstances, such as availability of biomass, e.g from forestry, access to geothermal resources, subsidization of renewable energy through feed-in power tariffs, *etc...* influence largely the share of renewables in the local energy mix.

On the side of applications for production of electricity from non-hydraulic renewable sources, the world chemical industry has already contributed in developing materials used for some solar cells like cutting etching and texturing chemicals to texture the silicon substrates, frames and adhesives, as well as fibers, coatings, binders and cement additives used in on-shore and off-shore wind turbines. With continuing investment in research, the chemical industry is expected to come up with important new contributions in the future, for example organic solar cells, especially if demand for renewable energy production is effectively encouraged without however leading to higher prices. This is discussed in more detail in the scenarios for the future.

Mobility

Transport is a major driver of the *growth* of GHG emissions in today's world, but this growth is already limited by the introduction of products of the chemical industry. Transportation by sea is a necessary component of international trade, especially for intercontinental transport of food, construction material, coal, oil, wood, and many manufactured products. Such transport is practically entirely driven by burning of fossil fuels thus generating ever increasing CO_2 emissions.

What is little known to the general public is the contribution of antifouling compounds produced by the chemical industry in making transport by sea more efficient. In addition to limiting corrosion, application of antifouling compounds limits the growth of marine organisms on the hulls of cargo vessels, such growth increasing friction. Without these compounds, fuel consumption would be 29% higher, as would the associated CO_2 emissions. Considering the GHG emissions associated with manufacture of the compounds, and the lifetime before renewal, these antifouling compounds gave a net GHG emissions abatement of about 0,19 billion tons CO_2e in 2005

The Solar Impulse prototype embeds high performance - low weight products and solutions by chemicals.

Road and air transport are both important components of world trade and significant growing contributors to world GHG emissions. Chemical industry products, polymers and other plastics, are increasingly used in the construction of automotive vehicles. To the extent that these materials replace steel, aluminium and glass, typically twice as heavy as the plastics, they enable significant reductions of weight of the vehicles. For the world automotive fleet, total weight reduction is about 8 million tons. This significantly reduces their fuel requirements and associated CO_2 emissions. Considering the mix of gasoline and diesel, considering also that some automobiles use fuel-containing ethanol with a lower carbon footprint, the fuel savings factor for a ton of weight reduction comes today to 3.5 litres per hundred km.

Two-thirds of the plastics used in the automotive industry go to manufacturers in Europe and Asia, only 19% to the US, but even in the US this amount to close to 2 million tons of plastics. Calculation of the fuel and CO_2 emissions savings made possible by the weight reductions due to the incorporation of plastics gives total gross savings of 129 $MtCO_2$ equivalent per year (about 5% of total road transport emissions, corresponding very roughly to the total emissions of 50 million automobiles driving 10,000 km). This is offset by the GHG emissions associated with production of the plastics. Although gross GHG emissions in the plastics production (65 $MtCO_2$ equivalent per year) are fairly large, they are only slightly larger than the GHG emissions associated with the production of the alternative materials (steel, iron, glass) not produced by the chemical industry, taking into account the disposal credit corresponding to recycling of scrap steel and especially aluminium. With these differences taken into account, production of plastics to lighten vehicles involves only 5 $MtCO_2$ equivalent per year more GHG emissions than production of the metal and glass that they replace. Net savings therefore are over 5 $MtCO_2$ equivalent per year.

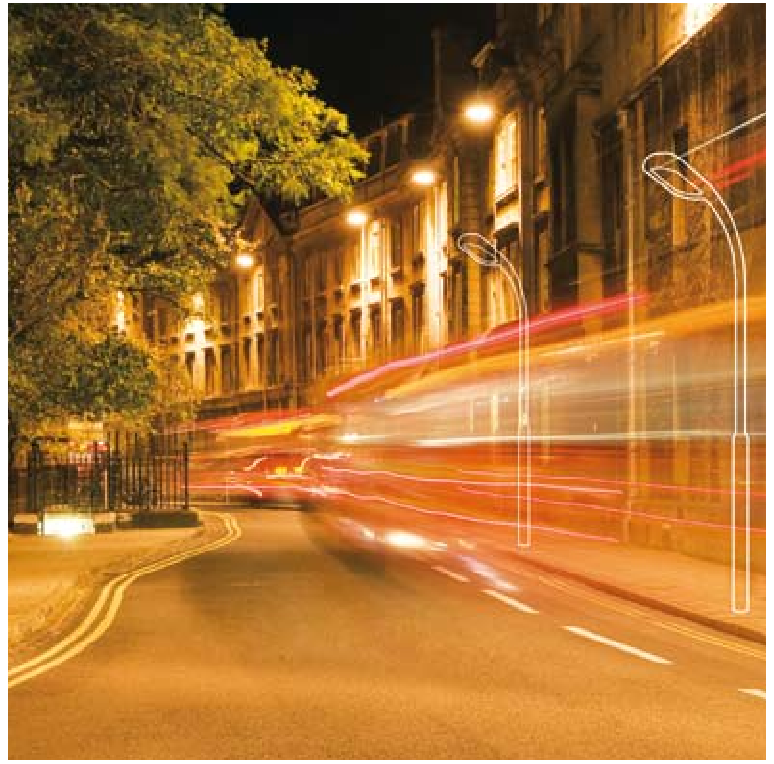
Apart from weight reductions, chemical industry products improve engine efficiency, either by way of fuel additives, or by way of improved lubricants. At present, synthetic lubricants account for only 7% of total global engine oil demand. Estimating that use of such lubricants reduces fuel consumption by 5%, and considering again the GHG emissions involved in producing these lubricants, the ICCA study calculates a global net emissions abatement of 17 $MtCO_2$ equivalent per year. Synthetic gasoline and diesel fuel additives also significantly improve fuel economy, by about 2%. This comes to a global net reduction of 28 $MtCO_2$ equivalent per year thanks to the use of gasoline additives, of 24 $MtCO_2$ equivalent per year savings made possible by diesel fuel additives. Altogether, where chemical industry products are used for lubrication and as fuel additives, fuel consumption is reduced by 7%. This corresponds not only to a significant reduction of GHG emissions, but also to a non-negligible reduction in the fuel bill. Chemical industry products also contribute to reduction of rolling friction in so-called *"green"* tires, again making GHG emissions reductions possible.

Weight reductions are also possible in aircraft, with carbon fibber replacing aluminium. A net emission abatement of 10 $MtCO_2$ equivalent per year is estimated. This could and indeed should grow in the futre, especially if the cost of aviation fuel increases.

Other chemical industry products enabling GHG emissions abatement

Numerous other chemical products are used in modern life, in packaging, textiles, and other consumer goods. In packaging, the use of plastics often allows reduction of weight compared to *"non-chemical"* alternatives (steel, tin, aluminium, glass, wood, carton, paper) and this reduces the transport load. When used for food, plastic packaging reduces food losses. The production carbon footprint is about 25% smaller for polymers than for the non-chemical alternatives, as are the GHG emissions at end of life, even taking into account the greater recycling rate for metals. The in-use savings from plastic packaging come out to 0.3 tCO_2 equivalent ton of packaging material. With over 90 million tons of polymer packaging materials produced in a year, the savings come to over 27 $MtCO_2$ equivalent.

Another example from everyday life is the use of synthetic low-temperature detergents for washing laundry. Both the production and the end-of-life carbon footprints of such detergents are substantially smaller than for soap, 11 against 49 $MtCO_2$ equivalent for 158 billion wash loads. In-use savings, calculated from the reduction in energy used to heat the water to 37°C rather than 60°C, come to 43 $MtCO_2$ equivalent. This corresponds to the dominance of fossil-fuel burning to produce electricity in the world, taking into account the zero GHG emissions associated with nuclear or hydropower.



With limited energy resources and strong dependence on import of petroleum and natural gas, Europe must continue to improve energy efficiency of its activities. Europe must produce more *"negawatts"* - saving power (thus negative watts or *"negawatts"*) and so reducing consumption of energy resources while better satisfying consumer needs. The European chemical industry's research and manufacturing capabilities are essential. The building-block status of the chemical industry in Europe, its cluster approach provides many products essential to the life of citizens and the competitiveness of the EU economy. Examples include a lot of chlorine compounds useful to many downstream users, as well as widely used strong lightweight plastics.

At least as important, although contested by some, are the contributions of chemical industry products to the development of agriculture that has made it possible for Europe to satisfy its own needs for food (except for tropical products), and in some cases play a role as exporter. Within a global framework discouraging carbon leakage, continued development of advanced European chemical products with low lifecycle carbon footprint will be essential to protect the competitive position of the European manufacturing sector and associated employment with minimal dependence on imported products.

In the area of fossil energy resource use, notably of still widely available coal, effective carbon capture and storage (CCS) technology needs to be rapidly developed. Efforts are under way the world over. A strong and innovative European chemical industry, contributing to CCS, could become a major technology exporter. Similarly, chemical industry innovation can contribute more to the harnessing of solar and wind energy.

Why a competitive EU chemical industry?

Although the climate change issue is global, is there room for a specifically European approach and set of solutions? If its solutions are good for reductions of its emissions, then they should be good for the rest of the world. Lacking fossil resources, the EU chemical industry was early driven by an energy efficiency policy and by research for innovative products. Contributing to 8% of EU Research and Development spending, this industry still directly provides jobs to 1.2 million people, adding 2 jobs in the service area for each job in the chemical industry. In 2005, the EU chemical industry was responsible for 38% of patents in chemical industry, excluding pharmaceuticals (source: Fraunhofer-Institute (ISI), calculation based on EPPATENT and WOPATENT). This industry reports the second highest added value per employee in Europe, after pharmaceuticals and before transport equipment. Such innovation pays off. Since climate change solutions need considerable research and development efforts, the management of emissions should preserve the competitiveness of places developing such solutions for the benefit of the whole economy.

The chemical industry also works to develop cleaner and safer technologies, waste recycling processes and new products to safeguard the environment (biotechnology processes, catalysts, membranes, desulfphurizsation plants, etc.). One aspect is increased energy efficiency. As a result, GHG emissions per unit of energy consumption have been reduced by more than 31% and GHG emissions per unit of production have been reduced by nearly 60% since 1990. In comparison to the US, where the chemical industry decreased its emission intensity (emissions per unit of production) by 36% since 1990, the EU reduced its GHG emission intensity much more (60%) and is today more GHG emission-efficient.

Thanks to such an innovation strategy, the EU chemicals industry has been able to pave the way to the low-carbon society, being for example a leader in the new tire technology that cuts greenhouse gas emissions from cars by 5%. The EU chemicals industry has also developed a tradition of improving building temperature management, for example by producing microencapsulated paraffin wax cells. In Europe again, the no-cost heating house is already a reality thanks to passive design and technologies that reduce heat loss.

The chemical industry provides direct and enabling solutions to reduce global GHG emissions while satisfying the needs of a growing world population

Efficiency in energy use reduces energy requirements for satisfying the essential modern life needs. Present technology, depending in part on materials and tools developed by the chemical industry, can strongly improve energy efficiency, but the potential improvement is only partly realized at present. Reduction of global GHG emissions depends in large part on improvement worldwide of energy efficiency, both by wider application of existing tools and by development of new ones. Even if global GHG emissions from energy production can be substantially reduced by a combination of hydropower, nuclear power, and non-hydraulic renewables, improving energy efficiency remains essential to a sustainable future.

The chemical industry develops tools to reduce emissions of carbon dioxide and to capture them in everyday life

Combustion of still relatively abundant coal, used to generate electric power in much of the world (China, India, US in particular), generates a greater and greater share of global GHG emissions. Only in the last decade or two has climate change concern led to the principle that CO_2 emissions constitute a waste product that should *not* be released to the atmosphere. Reconciling continued use of the coal resource (non-renewable, but unlikely to be exhausted before at least a century) with the imperative of reducing GHG emissions to the atmosphere requires rapid development of carbon capture and storage on a large scale. Chemical industry tools, existing or to be developed, can contribute to development and deployment of CCS systems.

The chemical industry develops tools to reduce emissions of carbon dioxide in everyday life

The development of chemical technology makes possible the use of carbon in place of metals in everyday-life tools, in particular automobiles, generally reducing the weight of these tools. This reduces energy demand in the transport and other sectors, thus reducing CO_2 emissions. Similarly, the use of advanced thermal insulation materials produced by the chemical industry makes possible maintenance of greater comfort in buildings at much lower energy cost for heating and cooling. In the area of lighting, chemical industry products are essential for the modern lamps replacing incandescent bulbs and producing the same useful illumination at much lower energy cost.

The important factor in all these cases is not the carbon actually used to make these tools, but rather the GHG emissions abatement linked to their use over their life cycles. In the industrialized countries, per capita CO_2 emissions amount to several tons per year, for the most part due to transportation and heating or cooling of buildings in addition to production of electric power in large part also used in everyday life. Real and potential reductions in these emissions are far larger than the carbon that could go into material making up automobiles or buildings considering their lifetimes.

Everyday life also produces waste, often involving health risks as well as emission of the powerful greenhouse gas methane. There certainly are possibilities of capture and use of the methane, and the chemical industry may be able to contribute more effective technologies. Apart from organic wastes, in many cases modern everyday life generates waste consisting of packaging materials produced by the chemical industry, as complex consumer goods (packaging, leisure, sports goods, electronic devices...), but not fully recycled. Here too the chemical industry can play a useful role in reducing space requirements for such waste by developing technologies for effectively recycling some of the materials. The contribution of external stakeholders such as municipalities or waste collectors can also help a lot.

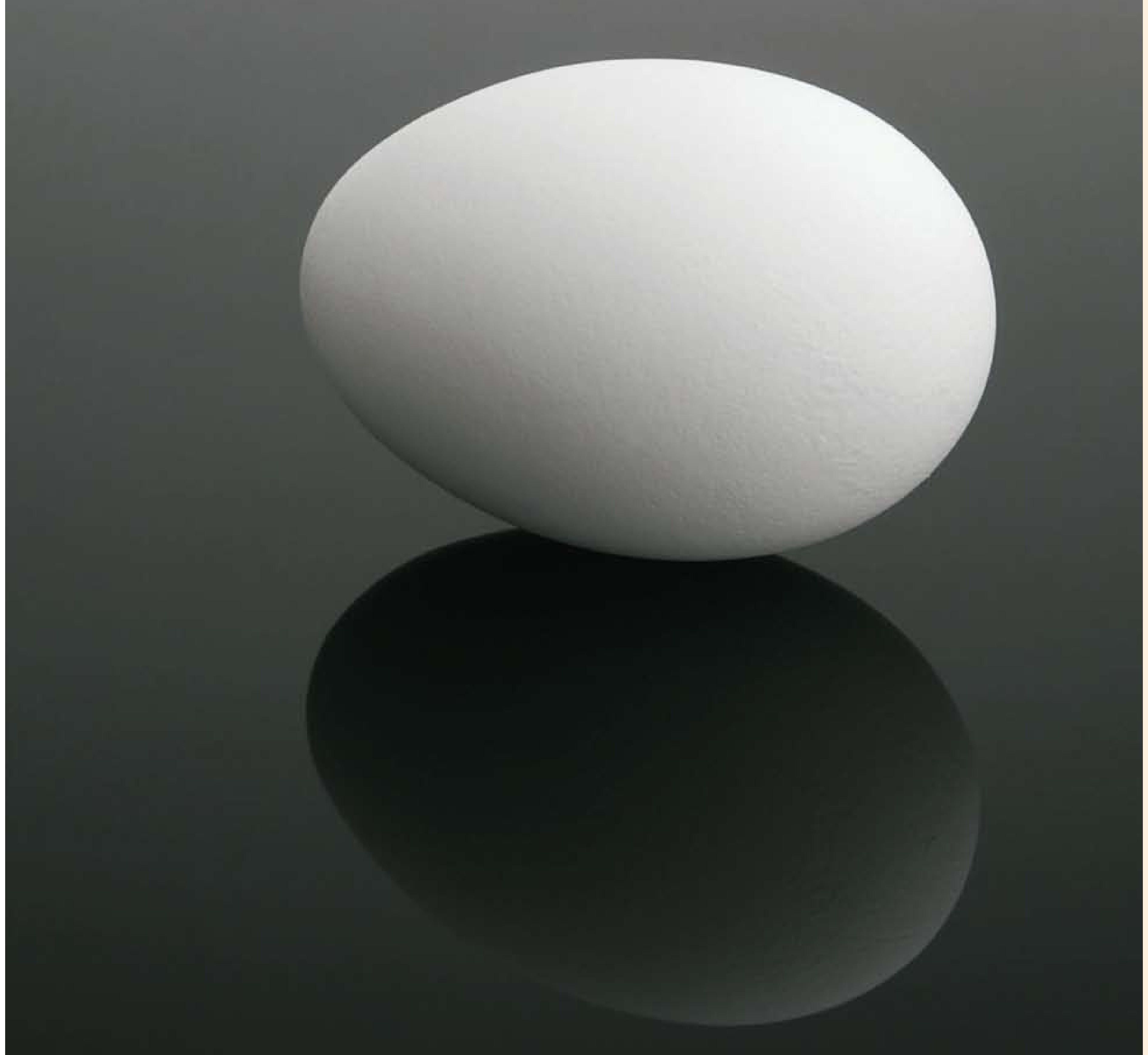
The chemical industry develops technologies that make possible more effective use of renewable energy resources

Large-scale exploitation of solar energy requires more effective and less expensive solar cells, and the chemical industry's contribution to these developments will continue to be essential. Also, it will play the key role in developing better (more efficient, lighter, longer-lived) batteries for storage of electric power. Such development is essential for many applications because of the intermittent nature of both solar and wind power. It also will make possible the development and wider use of (non-hybrid) electric automobiles, which require batteries with more capacity at lighter weight than presently available if such vehicles are to be used outside of urban settings.

In addition, although in some regions, electric automotive vehicles using nuclear- or hydro-generated electric power may reduce transport-related GHG emissions, replacement of petroleum-based liquid fuels by renewable fuels remains a priority. The presently used biofuels of the first generation (ethanol, *"biodiesel"*) will have to be replaced by more effective fuels with lower short-term and long-term carbon footprints, based on intensive cultivation of appropriate vegetation without negatively impacting food production and without excessively encroaching on remaining natural forest. Producing appropriate fertilizers and crop protection for cultivating such higher-generation bio-fuels (including forest plantations) on lands of lower quality constitutes a major challenge and opportunity for the chemical industry.

The chemical industry creates new materials while preserving the existing stocks of raw materials. Thus the challenge of stabilizing the climate can be a general opportunity for industry to provide more and better with less

A sustainable future depends on not exhausting non-renewable resources, in particular metals. Recycling is a part of the solution as is energy recovery. However, carbon is an abundant element on Earth, and the chemical industry has developed technologies that make use of this element in materials for important everyday-life tools. These include some of which the public is often unaware. Abundant carbon, used in new materials, thus already replaces relatively rare metals. More can be done, particularly considering that the geographical distribution of some metals such as lithium is even more restricted than that of petroleum. It must be noted however that the production at relatively low energy cost of new carbon-based materials depends in part on the availability of the hydrocarbon molecules in the feedstocks such as petroleum and coal. These feedstocks are at the same time the fossil fuels still used to produce energy in most of the world. Energy efficiency will help to delay their exhaustion. Together with society, the industry must also find better ways, more ecological and economical processes, to recover and use feedstocks from various forms of waste presently not being recycled.



Chemistry and our climate future

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- Harmonized global policies for global markets
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- Support the development and implementation of new technologies
- Support the development of the most efficient and sustainable use of available feedstocks
- Provide incentives for faster action by rewarding early movers
- Push for the most efficient and sustainable end-of-life solutions
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- Conclusion

Present global use of fossil energy and related GHG emissions are not sustainable in the long term (100-300 years) because of the non-renewable nature of fossil fuels. They are also unacceptable in the short term (30-100 years) because they induce irreversible climate changes which, even if they are not catastrophic, will be too strong and too rapid for *"painless"* adaptation by much of the biosphere and many human societies. Growth predictions and energy consumption forecasts (IEA World Energy Outlook) i.e. for emerging economies and developing countries imply dramatic emission increases by far exceeding those of the 'old' developed economies. The challenge is how to curb such emissions effectively in the coming decades. The study carried out by Mc Kinsey on behalf of the International Council of Chemical Associations investigated the role of the chemical industry in two scenarios for the near-future trends (2030).

A *"business-as-usual"* scenario, which would emit increasing quantities of GHGs that would negatively impact the sustainability of the development of mankind

The *"business-as-usual"* scenario used for the period 2005-2030 in the ICCA study assumes a global gross domestic product (GDP) growth rate of 3% per year, and assumes that this also applies to the chemical industry.

At any rate, much of the GDP growth is likely to take place in China, India, and more generally in the Asia-Pacific area. In much of this area, at least in China and India, carbon intensity of energy and wealth production is presently very high. Thus the geographically differentiated *"business-as-usual"* scenario will almost certainly lead to continued strong growth of GHG emissions.

At the same time, a *"business-as-usual"* scenario with increasing demands on fossil fuels for energy production will almost certainly involve a continuing upward trend in the price of energy, increasing pressure for energy efficiency innovations in the chemical industry as well as in other industries. This increasing demand will also stimulate reduction in the carbon intensity of energy and wealth production, especially in the emerging economies.

But this will not be enough to ensure sustainable development. Continued growth of GHG emissions will lead rapidly – certainly within this century – to rapid strong changes of the climate map and the risks of weather-related disasters, imposing new difficulties for the biosphere and for human societies. In addition, continued growth of the use of fossil fuels will accelerate the exhaustion of these non renewable resources – especially easily accessible petroleum and natural gas - and is incompatible with sustainable development in the medium and long term.

An abatement scenario, necessary to reduce the risk of severe climate change

Substantial abatement of GHG emissions requires identifying new modes of development for human societies, and a new role for chemical industries in particular. There is a huge potential for reductions in GHG emissions by the chemical industry, both directly and especially by way of its products. This potential can be greatly enhanced by sound policy decisions that *"incentivize"* the chemical industry to employ more sustainable processes and supports extended use of products enabling more sustainable climate change solutions. Such an evolution requires stable framework conditions and a level playing field on a worldwide basis.

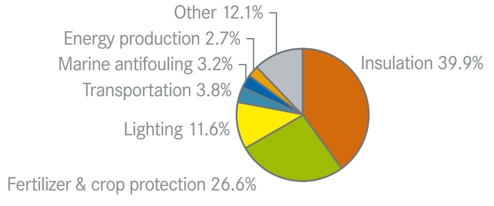
In particular, it should not accept simple export of high-carbon-footprint activities from countries enforcing low-emission policies to others. This must be accompanied by policy decisions requiring or at least strongly encouraging the use of products with smaller carbon footprints in all sectors of activity, industrial, agricultural, and services, and in development of new infrastructure, so that demand for products with low life-cycle carbon footprints grows. Growing consumer awareness of the need to lower carbon footprint will feed this growth of demand. Chemistry will feed the changes in all other industrial sectors... and in new industrial sectors. Chemistry is here a bridging technology for multisectoral climate protection.

Future trends in emissions by the chemical industry

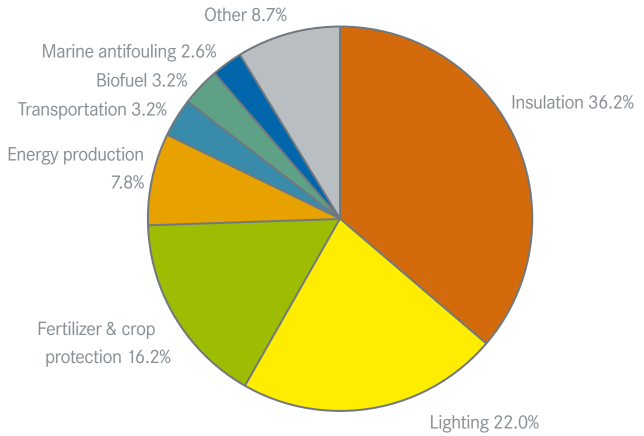
In the ICCA study, *"the abatement scenario... assumes effective implementation of measures leading to a low-carbon economy. Such measures include globally consistent regulation and initiatives that incentivize the reduction of the industry's CO_2 equivalent emissions, and regulation to increase the use of products and applications with a positive abatement effect"*. Whereas in the *"business-as-usual"* scenario, growth of the high-carbon-intensity economies of China and the Asia-Pacific region limits the GHG emissions abatement that can be achieved globally, the ICCA abatement scenario assumes that *"globally consistent regulation and initiatives"* lead to application of GHG emissions abatement measures *worldwide*, with significant reduction of carbon intensity in China and elsewhere, including Eastern Europe.

In the *"business-as-usual"* scenario, world chemical industry output grows by about 100% between 2005 and 2030, nearly doubling the chemical industry's own GHG emissions from 3.3 to 6.5 $GtCO_2$ equivalent per year. In the abatement scenario, chemical industry output grows even more than 100%, but its own GHG emissions are limited to 5.0 $GtCO_2e$/yr. Moreover the payback ratio of gross life cycle emissions savings to chemical industry emissions goes from about 3 in the *"business-as-usual"* scenario to more than 4 in the abatement scenario (4.7 including fertilizer and crop protection).

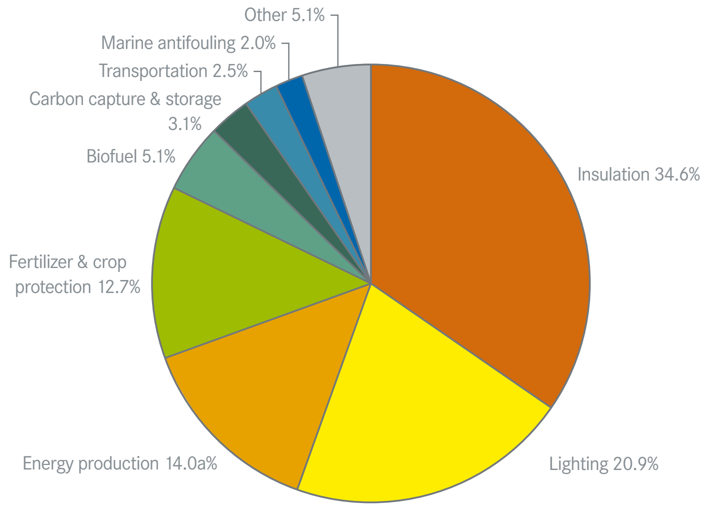
Greenhouse gas emissions savings enabled by chemical industry products in 2005 compared with those estimated in 2030 for differents scenarios



2005
6,010 million tons of carbon dioxide equivalent



2030 - "Business as usual" scenario
15,450 million tons of carbon dioxide equivalent
2.57 fold savings enabled in 2005



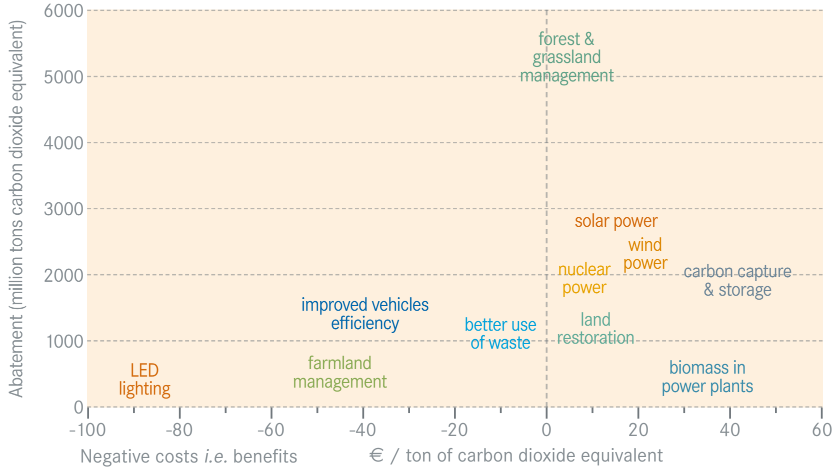
2030 - Abatment scenario
19,650 million tons of carbon dioxide equivalent
3.27 fold savings enabled in 2005

Graphic size is proportional to the savings enabled.
Source : ICCA Report

The global all-sector emissions abatement scenario includes some measures that pay directly for themselves from the business point of view, for example improvements of motor systems in the transport sector, better thermal insulation in the building sector. Wider use of thermal insulation foams produced by the chemical industry is the major life cycle emissions abatement lever. The European chemical industry should be in a good position in the global market, while at the same time one may note that installation and upgrading of building insulation is a positive factor in local employment.

Another strong life cycle emissions abatement lever is the replacement of incandescent and CFL lamps by still more energy-efficient LEDs and the fact that solar and wind power can grow to the point of producing 25% of worldwide electricity by the year 2030.

Some examples of abatement scenario costs



Source: ICCA Report

The abatement scenario thus includes, in addition to measures that pay for themselves, other measures that appear more or less costly from the business point of view. For the chemical industry, certain emissions abatement levers appear extremely costly, in particular certain chemical process intensifications, catalyst optimization, ethylene cracking, and most hypothetical, large-scale carbon capture and storage (CCS). The potential emissions abatement of CCS is very large, and the ICCA study assigns 20% of this to the chemical industry, but its feasibility is far from proven, and the cost is estimated at over €100 per ton CO_2 equivalent emissions.

Implementation of all the emissions abatement *"levers"* will of course depend on technological advances. For some of the most powerful levers, it will also depend on creation by governments of conditions favorable worldwide to the bridging of the gap between business costs of € 100 or more per ton of CO_2 equivalent emissions and societal costs evaluated at € 50/tCO_2e or less (*cf.* ICCA Report, Exhibit A.III.1). In the abatement scenario as in the *"business-as-usual"* scenario, growth of energy efficiency as well as reduction of carbon intensity of energy production results in significant emissions abatement. However, in the abatement scenario, the further increases in energy efficiency and the wider uses of energy-efficient chemical industry products yield further emissions abatement amounting to 4.7 billion tons CO_2e per year allocated to the chemical industry, a significant fraction (12%) of the overall emissions abatement across all sectors of activity.

The abatement scenario detailed in the ICCA study may appear timid to some observers, who will judge it not sufficiently ambitious in terms of the imperative to begin reducing global GHG emissions by the year 2030 if one seriously wants to avoid dangerous global warming in excess of 2°C. At the same time, others may consider it to be optimistic in terms of what is likely to occur, considering the supposed costs of abatement. The challenge for the chemical industry is to recognize the need for emissions abatement and to seize the opportunity it affords.

The chemical industry will have to deal with issues such as:

1. The need for new materials and the cohabitation with existing materials. A balance to improve. The abatement scenario includes only scientifically proven technologies leading to new materials commercially available by 2030. Continuing research on breakthrough technologies can be expected to lead to materials and processes yielding even greater GHG emissions abatement potential in the areas of solar cells, batteries and fuel cells, and electronics, as well as water desalination. The new materials and processes will have to compete with those already on the market and in some cases cohabitate with those already in use.

2. The need for and the rise of new consumption modes. Chemical industry products will continue to face cohabitation with *"natural"* plant and animal materials for many everyday consumer products such as textiles and furniture, with fashion driving many consumer choices. In the essential everyday area of food, because of the large direct and indirect GHG emissions (and use of water, land, and other resources) associated with the choice to consume meat, the emissions abatement associated with fertilizers and (animal feed) crop protection will depend strongly on whether meat consumption continues to rise worldwide or whether a choice to go vegetarian takes hold among those who can afford meat.

3. The need for adaptable solutions. Breakthroughs in the energy field may reduce the demand for fossil fuels and the associated GHG emissions. Unavoidable climate change may reduce needs for space heating (but increase that for air-conditioning). Renewable raw materials will be increasingly important for the chemical industry.

4. The need to use resources more sparingly. Enhanced energy efficiency will always be an advantage, even if nuclear and renewable energy resources largely replace fossil-fuel burning generating CO_2 emissions. The same applies if large-scale CCS becomes a reality. Similarly, more efficient use of fossil feedstocks, and their replacement by recycled materials or by renewable *"bio-feedstocks"* could be a priority from wide scale to niche markets. Other solutions will also contribute. Finally, the task of adequately feeding a still-growing world population must be assured with efficient use of land and water.

5. The need for continually improved and more sustainable products. Penetration of the precautionary principle maintains the efforts of the chemical industry to ensure enhanced product safety and to further implement a sustainable development policy.

Harmonized global policies for global markets

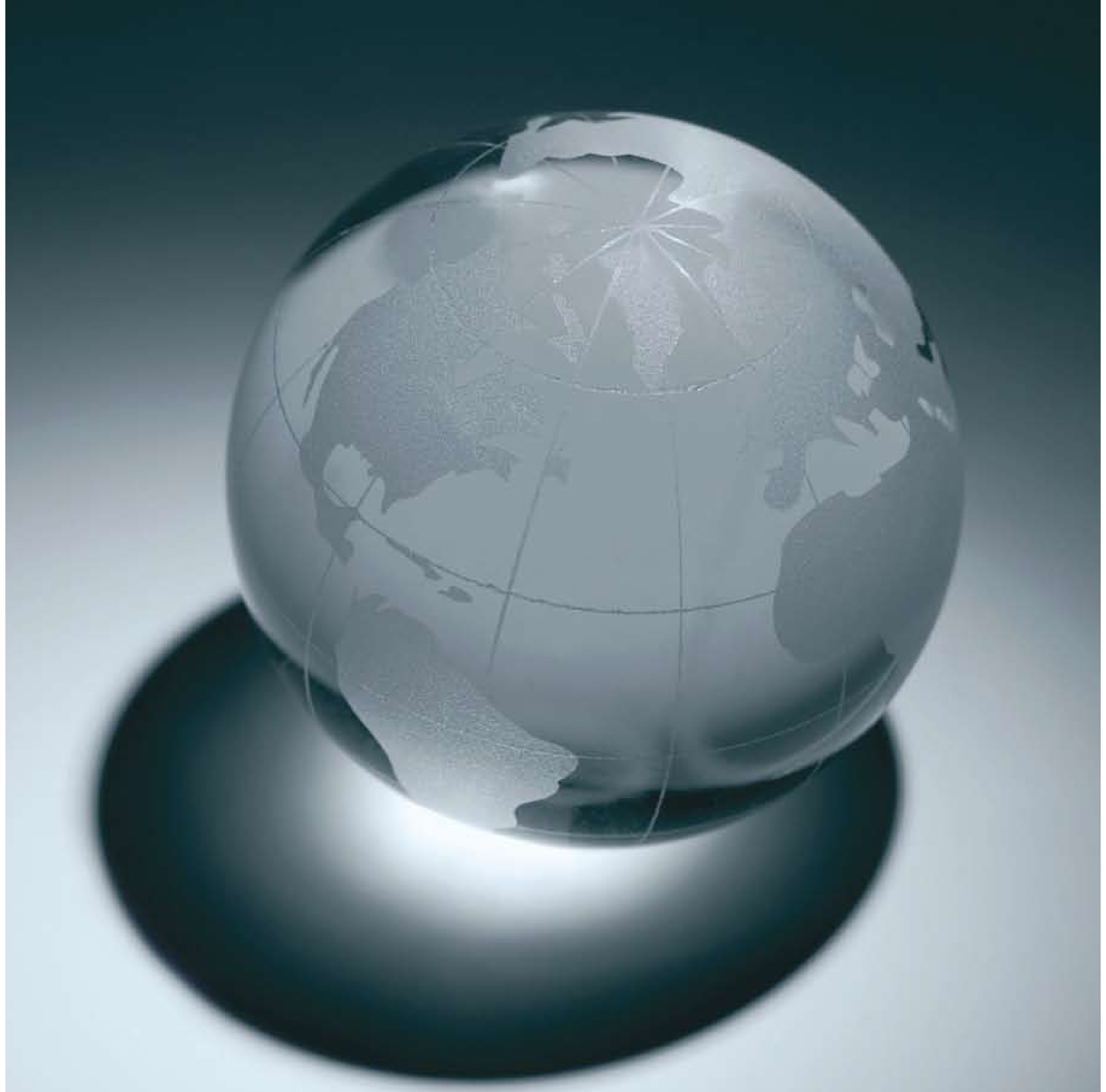
Ending man-related reinforcement of the greenhouse effect is a global challenge. Mankind's industrial, agricultural, and other activities giving rise to emissions of carbon dioxide and other greenhouse gases are unevenly distributed over the globe, but the circulation of the atmosphere homogenizes the distribution of those added gases. The trap to be avoided is transfer of production from countries or regions enforcing strict carbon footprint limitations to other areas with less stringent regulation.

Such *"carbon leakage"*, which could result from global market competition in the absence of global carbon policy, needs to be avoided by a negotiated mix of regulation, tariffs, subsidies, and taxes. One should note that taxes are disputed on many sides, in particular by several stakeholders from within the industry who prefer a cap-and-trade system for emissions reductions. In such a system, the cap is the limit on the total amount of GHG emissions. GHG emitters defined in the legislation must hold allowances (either allocated or purchased) equal to or greater than their emissions. Certificates for GHG emissions are traded in an auctioning system. Other observers, however, dispute the efficacy of cap-and-trade for GHG emissions abatement. The solution is an enforceable global CO_2 regime.

For everyday life, one may note that in Europe, energy labelling has led to increased sales of the most energy-efficient appliances and disappearance from the market of the least efficient. Although there is not yet any uniform agreed standard of GHG emissions labelling, it has begun to appear with regard to fuel consumption of automobiles. Requirement and generalization of some appropriate *"carbon"* labeling could be a factor favorable to use of low-carbon-footprint materials in consumer products, not only automobiles.

The framework to be constructed must govern the full lifecycle carbon footprint of chemical (and other) industry products, including not only their extraction, production, and disposal phases, but also the greenhouse gas emissions during the life of the products or services in which they are used.

At the same time, the world is changing. Measures must be implemented to transfer low-carbon-footprint technology to emerging economies, while at the same time not discouraging investment in further developments of such technology in the advanced industrialized countries



Policy recommendations: creating a proper society environment to provide solutions

Focus on the largest, most effective and least costly GHG-emissions-abatement opportunities

Many of the GHG-emissions-abatement opportunities have negative cost (which means in fact benefits) when the full life cycle is considered, and industry will naturally focus on these provided there are no artificial or irrational obstacles. In the scenarios examined in the ICCA study, and also in an optimistic *"breakthrough"* scenario with strong penetration of renewable energy sources, building and other thermal insulation constitute the largest and most effective abatement opportunity. The second most important abatement opportunity, again with benefit rather than cost, is in the area of lighting. Similarly with negative cost is the penetration of chemical industry products in the sectors of transport, especially road transport.

According to some calculations, agricultural applications – fertilizer and crop protection – are the second most important area of GHG emissions abatement. In (mostly tropical) poor countries, improved access to and use of agrochemicals can reduce deforestation associated with expanding conversion to slash-and-burn agriculture. This can yield strong emissions abatement (about 2 billion tons CO_2 equivalent) at very low cost. This should be recognized as a priority area for aid to such countries; it requires recognition that such use of agrochemicals can protect the natural environment.

Similarly, the ICCA study finds some small abatement opportunities at negative cost in improving crop nutrient management and also tillage and residue management. These should be pursued, particularly as they may help deflate some of the objections, on ecological grounds, to intensive agriculture. The same is the case for some other low-cost (less than €15 per ton CO_2 equivalent) operations in the direction of improved land management: restoration of organic soils, reforestation of degraded lands, and afforestation of pastureland. Higher costs (€30/tCO_2e) are estimated for more radical changes in intensive agriculture, but the GHG-emissions abatement of about a billion tons CO_2e together with the calming of some ecological fears justifies pursuing these.

The study finds non-negligible costs (but still less than €25/tCO_2e) in some wind and solar energy developments already in the pipeline, developments that could lead to large GHG-emissions abatement of order several billion tons. Given the risks of continuing increase of GHG emissions, these areas merit attention and investment.

Uncertainty remains concerning feasibility of development, in the next few decades, of large-scale carbon capture and storage; high costs are currently estimated for CCS implementation. However, prospective emissions abatement of billions of tons CO_2 equivalent justifies pursuit of this goal, considering that such abatement can make continued use of available coal resources acceptable. As an option, it should be possible to finance expanded CCS research and development by taxing the exploitation of coal.

Push for energy efficiency

Even if development of nuclear and renewable energy reduces the carbon footprint of energy production, energy efficiency will remain a priority. Improved energy efficiency reduces pressure on land, water, and other resources such as uranium as well as coal and oil. In any case, in the present and near-future world, energy efficiency goes with GHG-emissions abatement, and use of chemical industry products in insulation and lighting is a major driver of both energy efficiency and GHG-emissions abatement.

Support the development and implementation of new technologies

Much is in the pipeline, but much more is needed to strongly reduce global GHG emissions while improving living standards for the world's population. Research and development of new technologies are essential if carbon capture and storage is to become a large-scale reality, and not just an acronym.

In the longer-term future, sustainable development requires that renewable energy sources cover energy needs, and chemical industry research and development will play a role in larger-scale and more efficient exploitation of solar and wind power, as in the development of higher-generation biofuels with limited pressure on food-producing land. Ongoing research indicates that imitating certain biological processes can lead to much more efficient *"organic"* solar cells. Translating these results into reality will depend on what is done in the chemical industry.

Production of electric power from dispersed renewable sources will require development of new power transmission infrastructure.

Support the development of the most efficient and sustainable use of available feedstocks

As with energy, the long-term future is for renewables. Even if carbon is common on Earth, the feedstocks constituted by the more elaborate hydrocarbon molecules now wastefully burned are not so common, and they are not renewable on timescales less than tens of millions of years. Such feedstocks are far better used in chemical industry products enabling reduced energy consumption and GHG emissions in human activities. Imposing uniform full lifecycle carbon footprint limitations can support this energy efficiency and GHG-emissions abatement.

Provide incentives for faster action by rewarding early movers that proactively reduce their GHG (equivalent CO_2) footprint, both within the chemical industry and among actual or potential users of chemical industry products

Because many actions to reduce carbon footprint require investment, there need to be incentives in part provided by taxation and/or penalization of continued heavy footprint, in part by tax advantages or low- or zero-interest loans. One example is in the upgrading of building insulation, for residences (including secondary residences) as well as office buildings and factories. Another is in the construction of new renewable electric power generation and transmission infrastructure. Such upgrading and construction activities are generally positive factors for local or regional employment.

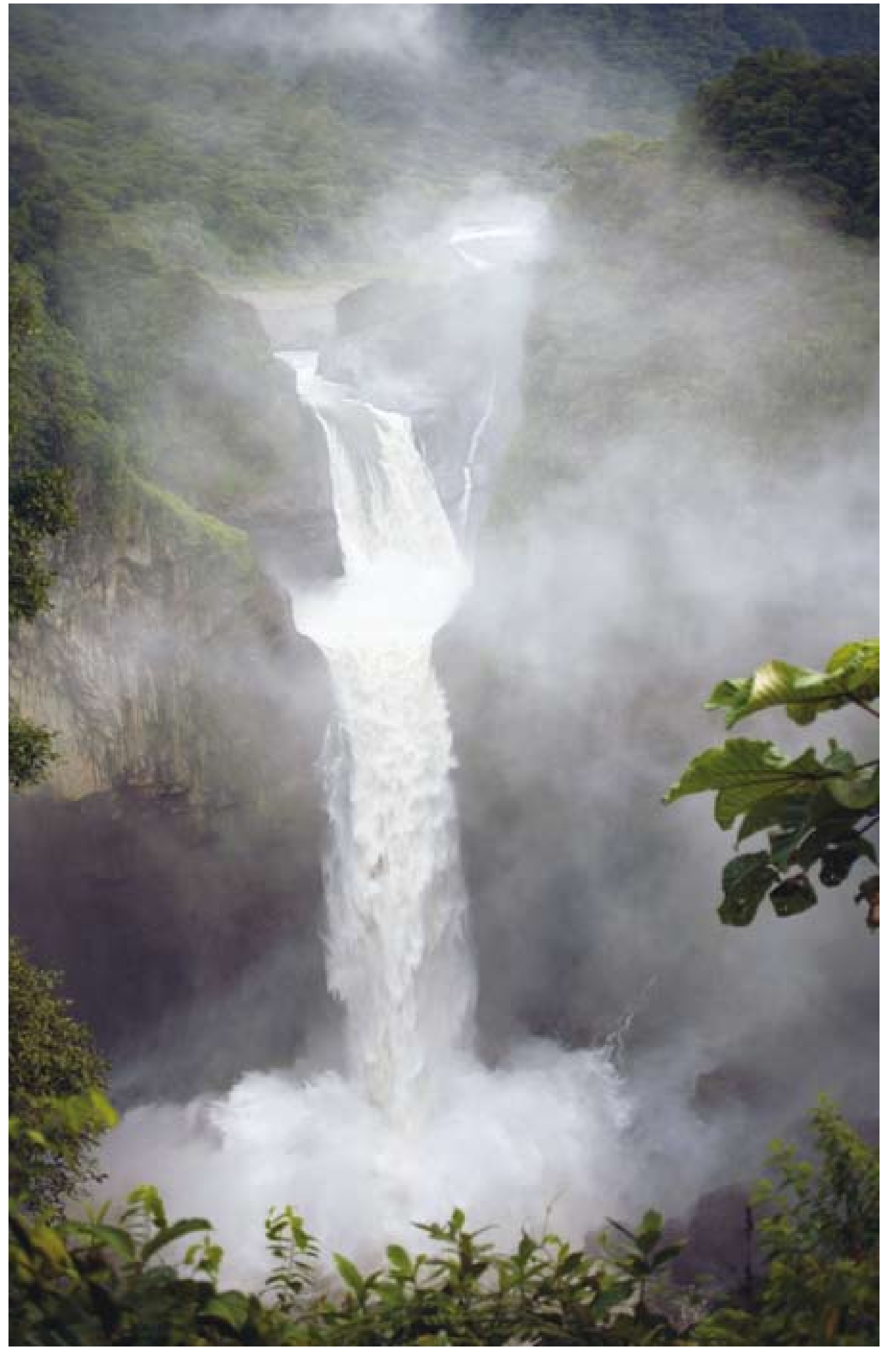
Push for the most efficient and sustainable end-of-life solutions

In each stage of the product´s lifecycle, the target is to maximize the efficiency in use of resources, where primary energy resources are key. In many though not all cases, depending on energy costs, recycling of plastics could be pushed to higher levels if a true sustainable energy efficiency is developed. In some cases, disposal should involve incineration, preferably contributing to urban heating systems.

Technology cooperation to support abatement in developing countries

Developing countries must be helped as well as pushed to implement low-carbon-footprint practices. This will not be easy. Despite the defects in the *"Clean Development Mechanisms"* instituted in the Kyoto framework, many observers argue that continuity must be maintained in the future framework under construction, so that the developing countries will not lose confidence in the emissions limitation process. Although technology transfer can reduce some competitive advantage of the advanced countries' industries, it is better than a trade war or other confrontations around carbon-footprint tariff barriers erected to bar *"carbon leakage"* to high-carbon-footprint industry in less developed countries. Intellectual property rights should at the same time be properly safeguarded to reward companies that have invested in responsible low-carbon technologies.

The right policy environment will enable ongoing improvements in production technology and in-product performance by the chemical industry. This will be important to achieving an overall reduction in its own emissions. It will also contribute to important increasing emissions savings afforded by incorporation and use of its products by downstream users.



Conclusion: Chemistry has an important role to play in enabling sustainable solutions to climate-change issues for everyday life

The main challenge is climate stabilization by reducing emissions of greenhouse gases. To avoid dangerous climate change, atmospheric GHG concentrations must be stabilized before the end of the century, and perhaps reduced to levels below those already reached in 2008. This requires that reduction of GHG emissions begin in industrially developed countries and before the year 2050 in the world as a whole.

Chemical industry processes and products both have an important role to play in climate stabilization. Chemical industry processes contribute a significant fraction of total anthropogenic GHG emissions, and this should and can be reduced. Many chemical industry products, in particular thermal insulation materials for buildings, and materials used in compact fluorescent lamps, already enable large abatement of GHG emissions over the life cycle of the products in which they are incorporated. Improvement and wider use of these products will be a significant factor in GHG emissions abatement over coming years and decades.

Success of the effort to reduce global greenhouse gas emissions will depend on the response of the chemical industry in answering the demands, needs and desire of the world's populations for existing and new innovative products that have smaller carbon footprints. Continued and intensified research in the chemical industry and in the user sectors is an essential part of the development of technologies both for more effective use of renewable energy resources with close to zero carbon footprint, and for the development of large-scale carbon capture and storage to strongly reduce net CO_2 emissions to the atmosphere even where fossil fuels are burned.

The figures of the GHG savings enabled by the chemical industry can be considered as encouraging but they do not match all the reductions needed to curb the general growth of emissions. The dissemination of current tools deals with current assets. But a special focus has also to be maintained on innovations to come in order to combine economic growth and sustainable development with regards to climate change. That is a topic mentioned by the ICCA report in scenarios for the future. Examples include totally new materials for advanced solar cells including organic photovoltaic systems that could greatly improve their efficiency. Under the right conditions, more innovations could be on the way. Getting to a low-carbon economy obviously requires such innovations.

Development of automobiles with smaller carbon footprints will depend on progress in battery technology as well as better fuel and lubrication additives, with major contributions by the chemical industry. Chemical industry products also respond to the need for increased food production and supply of clean freshwater for growing populations.

In all these areas, major breakthroughs are possible if sufficient resources are committed to research and supported by policy decisions enabling this route to be followed.

Professor Robert S. Kandel

Robert Kandel is emeritus senior scientist at the Laboratory of Dynamic Meteorology (LMD, Ecole Polytechnique, Palaiseau). Born in New York and a Harvard graduate in astronomy, he earned a doctorate in astrophysics working at the Paris-Meudon Observatory (France). After postdoctoral research at the NASA Goddard Institute for Space Studies (New York), he taught astronomy at Boston University (US) from 1969 to 1974. There, following the first Earth Day in 1970, he created a new course on the global environment. In France again after 1974, he switched to climate research in 1978, specializing in observation of the Earth from space and working in particular with the NASA (US) teams measuring the Earth's radiation budget (i.e. the planet's reflection of solar radiation and emission of infrared radiation to space). With support of *CNES* (the national space agency of France) he led the French-Russian-German *ScaRaB* mission measuring the radiation budget with an instrument built at LMD on board the Russian Meteor satellite. Robert Kandel collaborated with ESA and JAXA (the space agencies of Europe and Japan) in preparation of the future *EarthCARE* mission for observation of interactions between clouds, aerosols, and radiation.

In addition to his research and lectures at Ecole Polytechnique, Robert Kandel has served and continues to serve on numerous national, European, and international science councils, steering committees and working groups, contributing in particular to the review process for the Working Group 1 (Science) assessment report of the Nobel-Prize-winning Intergovernmental Panel on Climate Change (IPCC). He has taught courses on the atmosphere and climate at the Université Pierre et Marie Curie (Paris-6), Virginia Polytechnic Institute and State University (Blacksburg), ESME Sudria (Ivry), and at seasonal schools in Austria, France, Italy, Poland, and the UK; he has also lectured on climate and radiation issues in Belgium, Canada, Germany, Israel, Japan, the Netherlands, Russia and Switzerland.

Strongly committed to the popularization of science, Robert Kandel was awarded the *Prix Roberval* in 1990 and a *Prize of Scientific and Technical Culture* of the Ministry of Education, Research and Technology (France) in 1999. His books include *Earth and Cosmos* (Pergamon, 1980), *Le Devenir des Climats* (Hachette, 1990; in English as *Our Changing Climate*, McGraw-Hill, 1992; also transl. in Japanese and Portuguese), *L'Incertitude des Climats* (also transl. Italian) and *Les Eaux du Ciel* (Hachette, 1998), the latter as *Water from Heaven* (Columbia University Press, 2003, 2006), and *Le Réchauffement Climatique* (*"Que sais-je?"* series, P.U.F., 3rd edition 2009; also transl. in Portuguese and Greek). He also contributed to *The Ideas of Water* (Østigard, T. & T. Tvedt, Eds. London: I.B. Tauris, 2009, in press).

Glossary

Aerosols
Solid particles or liquid droplets suspended in air. Cloud water droplets and ice crystals are usually considered separately, although they too are aerosols.

BAU
Business-as-usual scenario. Assumes continuation of trends of the past 30 years and implementation of current policies only – no additional policies.

CARBON ALLOWANCES
These are the units exchanged or traded in the system managing greenhouse gas emissions in terms of CO_2 equivalence. They fix limits to be respected in a certain period for a certain geographical or professional sector. Such limits are enforceable by public authorities.

CCS
Carbon capture and storage (or sequestration): preventing carbon dioxide from fossil-fuel burning from reaching the atmosphere and storing it in a form and place from which it cannot reach the atmosphere for at least a few centuries.

CFC
Chlorofluorocarbons, artificially created molecules with the same structure as methane (CH_4) but with the hydrogen atoms replaced by chlorine and/or fluorine atoms.

CFL
Compact fluorescent lamp. Type of fluorescent lamp that fits into a standard light bulb socket or plugs into a small lighting fixture, providing more visible light (lumens) for given power consumption (watts).

cLCA
Carbon Life cycle analysis: assessment that focuses only on the CO_2 equivalent emissions (see LCA).

CO_2e
Carbon dioxide equivalent - Quantity that describes, for a given mixture and amount of greenhouse gases, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (in this project 100 years).

EMISSIONS TRADING
The aim of Emissions Trading is to help governments achieve compliance with their international climate policy goals, *i.e.* their national emissions reduction commitments. Emissions trading should allow for cheaper compliance with these targets. The idea is to limit greenhouse gas emissions (from the energy and industrial sectors) through the allocation of allowances to individual installations, thereby creating scarcity, so that a functioning market can develop later and overall emissions are then really reduced. Emissions Trading obliges the operators of GHG-emitting installations (*e.g.* combustion plants, oil refineries, coke ovens, iron and steel plants, cement, glass, lime, brick, ceramics, pulp and paper factories, chemical plants) to submit for compliance emission allowances for a certain period according to the emissions they generated. Letting participating companies buy or sell emission allowances means that the targets can be achieved at least cost, as proved to be the case for acid-rain-causing sulphur d ioxide emissions in the U.S. (*cf.* Science, 282, 1024-1027, 6 Nov. 1998.)
The emission allowance price should be a function of supply and demand as in any other market. The granting of free allowances can bridge a transition period to avoid "*carbon leakage*" - meaning the relocation of manufacturing to regions without equal burden - until a global emissions trading market is developed and functioning properly (same cost burden and carbon price).

GHG
Greenhouse gas - Generally, this refers to a gas which absorbs and emits thermal infrared radiation, *i.e.* a gas of polyatomic molecules (made up of more than 2 atoms); thus nitrogen (N_2) and oxygen (O_2) are not greenhouse gases. In discussion of anthropogenic emissions, this refers to *"well-mixed"* greenhouse gases.

GHG cost curve
McKinsey global greenhouse gas cost curve v.2, estimating the cost (or benefit) of implementing individual GHG emissions abatement measures. The cost curve was published in February 2009.

Gt
Gigaton: one billion tons.

IN-USE PHASE
Phase in life cycle in which product is being *"used"*, *i.e.*, after production and before disposal.

HCFC
Molecule similar to a CFC but with at least one hydrogen atom as well as chlorine and fluorine atom(s) around the central carbon atom.

IPCC
The Intergovernmental Panel on Climate Change (IPCC) is an intergovernmental body of scientific experts tasked to evaluate the risks of climate change caused by human activity. Working group 1 (WG1) deals with the physical science of climate change; WG2 with the impacts of anthropogenic climate change; and WG3 with possible strategies for mitigation and adaptation.

IPCC AR
IPCC Assessment Report - The most recent (AR4) was released in 2007.

Land-use change
Changing use of land from grass/forest land to cropland (or, rarely, vice versa). PAS2050 gives guidelines for calculation of CO_2e emissions arising from specified changes in land use for a selection of countries.

LCA
Life cycle assessment. Investigation and evaluation of the environmental impact of a given product or service caused or necessitated by its existence.

LED
Light-emitting diode, light source providing equivalent illumination with even less energy consumption than a CFL.

LGM
Last glacial maximum, about 18,000 years before the present.

LOW-CARBON ECONOMY (LCE)
Refers to an economy with minimal greenhouse gas emission especially CO_2.

Mt
Megaton. 1 million tons.

MWh
Megawatt-hour (= 1,000 kilowatt-hours).

NEGATIVE COSTS
Benefits.

PAS2050
Publicly Available Specification (PAS) for a method for measuring the embodied CO_2e emissions from goods and services. Development of PAS2050 commenced in June 2007 at the request of Defra and the Carbon Trust. Defra is the UK government department responsible for policy and regulations on the environment, food and rural affairs.
The Carbon Trust was set up in 2001 by the UK government as an independent company. Its mission is to accelerate the move to a low carbon economy.

Well-mixed
Applied to greenhouse gases, this term means that the time of residence of the gas in the atmosphere is sufficiently long for the atmospheric circulation to distribute it evenly in the entire global atmosphere, even if the sources are extremely localized geographically. Carbon dioxide (CO_2) and methane (CH_4) are well-mixed GHGs; water vapor (H_2O), although a greenhouse gas, is not well mixed.

X: 1
X: 1 ratio. Compares the emissions of the chemical over its life cycle and the enabled gross savings. Any X: 1 ratio bigger than 1: 1 leads to net CO_2e savings.

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Mankind must face the reality and risks of climate change. Although meeting this challenge raises major difficulties and drives intense international discussions, climate change can be mitigated by using the right tools.

What does one really mean by climate change? What are the observations and what is the role of human activity?

In this book - *"Turning the tide on climate change"*, I, Robert Kandel, a senior scientist who spent years working on climate, explain the scientific rationale that led the Intergovernmental Panel on Climate Change (IPCC) to the consensus that reinforcement of the greenhouse effect by human activities is the dominant cause of current climate change. I explain what these greenhouse gases are and what are their sources. There are serious risks of continued accelerated climate change, but if industry it part of the problem, is must also be part of the solution.

We all need to act, to change our behaviour and to find innovative solutions. Chemical industry is one of the key players. Of course, it uses fossil fuel for energy production and, as such, emits greenhouse gases. Nevertheless, the chemical industry shows the way to reduce our carbon footprint.

Indeed, the chemical industry can offer significant CO_2 savings through its products that are then used in every economic sector. Some examples are housing, mobility, renewable energy sources, recycling, farming, textiles, lighting, wind power... Abatement of greenhouse gas emissions enabled by the chemical industry is largely due to its strong R&D capacities. This innovation capacity must be maintained to provide tools for a more sustainable future, because further improvements are needed.

Because of expensive fossil energy and a strong demand for alternative solutions, the European chemical industry has developed a long tradition of research and development leading to innovative products able to reduce greenhouse gas emissions. For this innovative policy to continue to address our everyday-life needs while mitigating further climate change, there needs to be a constructive framework to avoid unfair competition and to maintain vigorous innovation activities. The industry has many downstream users: each of its improvements brings benefits to large parts of society and the economy.

Time for action has come. It will require a truly global policy framework to create the proper environment for sustainable development of human societies and efficient dissemination of low-carbon tools. This will require harmonized policy that will push for the most efficient and least costly greenhouse-gas-emissions-abatement opportunities, push for energy efficiency and support new technologies, development of the most sustainable use of feedstocks as well as end-of-life solutions. Rewarding early movers as well as helping developing countries by technology cooperation will also be essential.

Foreword by Dr. Rajendra K. Pachauri, Chairman of the Intergovernmental Panel on Climate Change