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*"The changes that are needed are, to a large extent, evolutionary rather than revolutionary."*
*Executive Director of the Internatnal Energy Agency, Claude Mandil*

## Energy challenges in the XXIst century (II): the quest for energy efficiency

- The world is not on course for a sustainable future: under current energy trends, energy demand will grow by more than half between now and 2030, causing global CO2 emissions to be 30% higher than their value today.
- Surging transport demand will continue to put pressure on oil supply and global carbon intensity will increase due to a greater reliance on coal for power generation mainly in Developing Asia and the USA.
- This can put the long-term balance of energy supply and demand in jeopardy and CO2 concentrations in the atmosphere could reach unsafe levels.
- But this alarming outlook is not destiny: things might and can change. The solution lies in a combination of both demand and supply side measures.
- The cheapest alternative is to improve energy efficiency. Some efficiency measures will require decades to have their full effect, but others can deliver significant positive results already by 2030.
- Extending the horizon to 2050 provides even higher scope for energy and emissions savings: CO2 emissions could be capped to their current level and the rise in energy demand could be brought to half its predicted value.

## Introduction

Current energy trends are unsustainable both from an economic and an environmental perspective: demographic and GDP forecasts point to a minimum 50% increase in primary energy demand between now and 2030, a raise that will be mostly covered by fossil energies. As a consequence, global greenhouse gas emissions (GHG) could rise by more than 30%, while experts are claiming for a 10% reduction to keep atmospheric concentrations at fair levels.

This booming demand could jeopardize long-term security of supply. Beyond concerns linked to the looming depletion of conventional oil and gas reserves (and their increasing concentration in a few remote and often politically unstable regions), there is in fact no guarantee that the incentives and opportunities to invest in new energy-supply infrastructure will be forthcoming on a timely basis and at reasonable cost, not to mention the huge amount of investment required to replace existing infrastructure already becoming obsolete.

The threats imposed by increasing energy costs, unreliable supply and global warming may reach a point of no return in a few decades if governments and private sector across the world do not steer the global energy system onto a more sustainable path.

In doing so, curbing energy demand by reducing the energy intensity[1] of the economies is the quickest and less costly alternative.[2] This can be mainly done through productive structure changes and/or through energy efficiency improvements (see Appendix). As we will see, the potential for improving energy intensity is huge in developed economies but it is even bigger in developing and transition ones, where changes in the productive structure and the modernisation of industries and infrastructures are a good opportunity to introduce higher efficiency standards.

This note explores the big potential of enhanced energy efficiency to curb overall energy demand and $CO_2$ emissions.

## A baseline approach to 2030 : IEA's Reference Scenario

In the past 25 years (1980-2004), world primary energy demand rose at an average annual rate of 1.8%. Although economic growth for the next 25 years (2004-2030) is expected to be higher (3.4% vs. 3.2%), the International Energy Agency (IEA) forecasts a smaller increase in energy demand (1.6% per year) thanks to a bigger decline in energy intensity (1.7% vs. 1.5%).(see tables 1 and 2) [3]

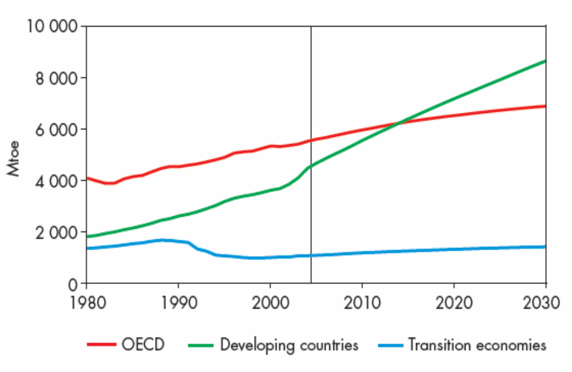
[1] The energy intensity of a process measures the quantity of energy needed to produce one unit of output. For the whole economy, it is calculated as the ratio between aggregated energy consumption and the country's GDP.

[2] Clearly, diversifying and decarbonising the energy supply is also a must. Potential for decarbonisation and diversification of the energy supply will be analysed in the third note of this series.

[3] Reference Scenario. World Energy Outlook 2006. IEA, November 2006. IEA's assumptions on GDP are taken from OECD.

**Figure 1**

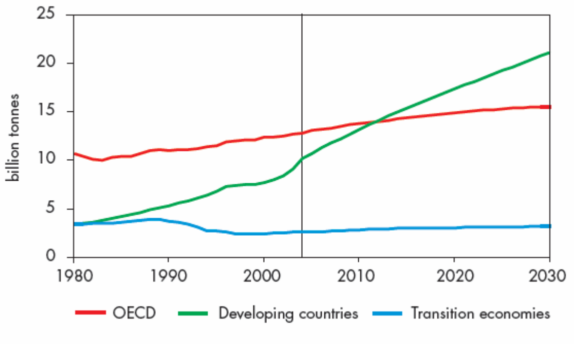
**World Primary Energy Demand (IEA Reference Scenario)**




**Source: WEO 2006. IEA.**

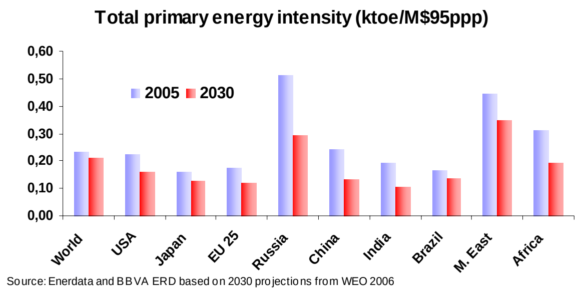
**Figure 2**

**World Energy-Related CO2 emissions (IEA Reference Scenario)**




**Source: WEO 2006. IEA.**

**Figure 3**



Still, under this scenario, world primary energy demand will be 53% higher by 2030. As in GDP, energy demand growth rates will be more accelerated in the first half of the period (2004-2015) and also significantly higher in developing countries than in developed ones.

In fact, more than 70% of the increase in world energy demand will come from developing countries, whose demand is set to surpass OECD levels already by 2015 (See figures 1&2).This will happen in spite of the fact that their primary energy intensities are set to fall far more rapidly than OECD ones as a consequence of a reduction in their dependence on energy-intensive industries, the removal of fuel subsidies and the adoption of more energy efficient technologies and standards, among others. This will be particularly remarkable in transition economies, where energy intensity could almost halve in the next 25 years. However, they will remain far more energy-intensive than developing and OECD economies by 2030 (figure 3).

By sources of energy, **fossil fuels** will remain the dominant supply source by 2030 and, as a consequence, energy-related **CO2 emissions will grow by 55%**. Oil will continue to be the most consumed fuel despite a reduction of its share on global primary demand. Still, the equivalent to the current annual production of three Saudi Arabias would be needed to meet the increase set in oil demand. Moreover, in spite of being the less efficient and most polluting fossil fuel, demand for old king coal is set to experience a big surge in countries with vast low-cost reserves such as China, India, Russia or the USA. Gas demand is set to grow faster than coal but does not overtake it before 2030.

As for **carbon-free energy sources**, nuclear and hydro will more or less maintain their shares over global primary energy demand in the reference scenario. Nuclear power production will decrease in the OECD but it will increase in Russia, China, Japan and South Korea. Non-hydro renewables will experience the biggest growth rate during the period analysed, but their small base will translate into a tiny share over energy supply still by 2030.

**Final energy demand** will rise by 1.6% annually. Among all major end-use energy sources, electricity is projected to grow most rapidly (2.6%, see table 3), especially in developing countries as electrification rates and incomes per capita rise. By 2030, the share of electricity in final energy use in these countries will almost reach that of the OECD (20%) but per capita consumption levels will still be much lower.

Not surprisingly, 47% of the total increase in primary energy demand will come from energy consumption in **power generation** and a further 20% from oil consumed in transportation. Fairly similar percentages apply to the expected increase in energy-related $CO_2$ emissions.

Given that the energy mix of developing countries will continue to be more carbon intensive (they use more coal and less gas than developed countries), these economies, mainly led by China and India, will overtake the OECD as the **biggest GHG emitters before 2015**, contributing to more than half of global GHG emissions by 2030 (compared to a current 40%). In fact, China's emissions will more than double between 2004 and 2030

**Table 1**

**Average yearly changes in 1980-2004**

| | GDP (constant 1995 PPP) | Energy Intensity | Energy Demand |
|---|---|---|---|
| **World** | 3,2% | -1,5% | 1,8% |
| **OECD** | 2,7% | -1,5% | 0,8% |
| **Non-OECD** | 4,1% | -1,8% | 2,4% |
| **USA** | 3,1% | -2,1% | 1,0% |
| **EU15** | 2,1% | -1,2% | 1,0% |
| **China** | 9,5% | -4,9% | 4,2% |
| **India** | 5,7% | -2,0% | 3,6% |
| **CEI** | 0,0% | -0,6% | -0,6% |

Source: Enerdata and BBVA ERD

**Table 2**

**Reference Scenario forecasts: Total Primary Energy Demand and Real GDP**

| (average annual growth rates) | 2004-2030 | |
|---|---|---|
| | **GDP** | **Energy** |
| **World** | 3,4% | 1,6% |
| **OECD** | 2,2% | 0,9% |
| **Developing countries** | 4,7% | 2,6% |
| **China** | 3,6% | 2,9% |
| **India** | 5,1% | 2,6% |
| **Russia** | 3,4% | 1,1% |
| **Brazil** | 3,0% | 2,2% |

Source: IEA, World Energy Outlook 2006

**Table 3**

**Reference Scenario forecasts: fossil energies and power**

| (average annual growth rates) | 2004-2030 | | | |
|---|---|---|---|---|
| | **Oil** | **Gas** | **Coal** | **Power** |
| **World** | 1,3% | 2,0% | 1,8% | 2,6% |
| **OECD** | 0,6% | 1,2% | 0,5% | 1,4% |
| **Developing countries** | 2,5% | 3,7% | 2,8% | 4,4% |
| **China** | 3,4% | 5,1% | 2,8% | 4,9% |
| **India** | 2,9% | 4,2% | 3,3% | 5,4% |
| **Russia** | 1,0% | 1,3% | 0,1% | 1,5% |
| **Brazil** | 2,0% | 3,8% | 0,9% | 2,4% |

Source: IEA, World Energy Outlook 2006

driven by strong economic growth and heavy reliance on coal in industry and power generation. Not surprisingly, coal will consolidate its position as the world leading contributor to energy-related $CO_2$ emissions.

## A roadmap to higher conservation

IEA's Reference Scenario projections to 2030 confirm that the energy path we are on is plainly unsustainable. In the absence of new policies, energy demand will continue to increase rapidly, and so will energy prices and import dependence. In addition to potential supply problems (conventional oil reserves will decline considerably unless significant new discoveries offset natural declines in production), the carbon intensity of energy supply will be bigger than today.

In the Reference Scenario, energy related $CO_2$ emissions will increase by more than 50%, pushing global emissions up by 30%. This contrasts sharply with the 10% reduction actually needed to get a chance to stabilise atmospheric GHG concentrations by 2050 at 550 ppm CO2e. The whole vision for the energy balance and emissions levels gets really sobering when we extend the forecasts on a "business as usual" basis to 2050. Disheartening as they may seem, we must say that IEA's estimates for energy demand and emissions growth are in fact on the low range of comparable forecasts provided by other organizations. [4]

However, these projections are not set in stone. The IEA reckons that, by adopting policies already enacted or under consideration, the world could reduce its energy intensity by 2.1% per year between 2004 and 2030 (compared to 1.7% in the Reference Scenario).

Under this "*Alternative Policy Scenario*", the world could reduce its primary energy demand by 10% with respect to the Reference Scenario (roughly China's today consumption), its oil demand in 13 mb/d (more than Saudi Arabia's current annual production) and its energy-related $CO_2$ emissions by 16% (half of today's OECD emissions. See figure 4).

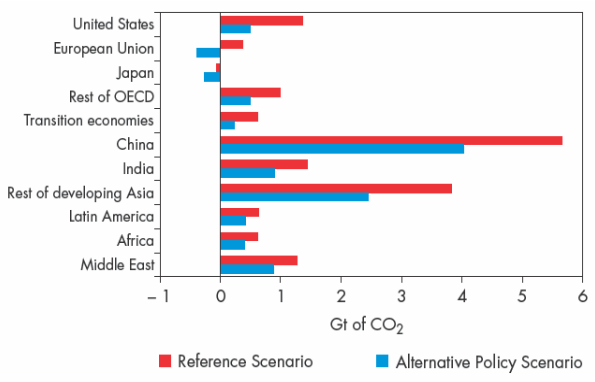
Overall, policies encouraging energy efficiency contribute the most to these potential savings (80% of avoided $CO_2$ emissions. See figure 5). Not surprisingly, these savings are relatively higher in non-OECD countries, reflecting their larger potential for energy efficiency improvements in power generation and end-uses, and the fact that additions to the physical capital stock are expected to be much larger than in the OECD countries.

Given that the cost of replacing capital stock prematurely is high (even when the new stock is more energy-efficient), savings would be considerably higher after 2015. In any case, investments considered in the *Alternative*

[4] For example, the US Energy Information Administration (IEA) gives a 2% average annual increase for world primary energy in its International Energy Outlook 2006 (IEO 2006) Reference Scenario for 2003-2030, which compares with a 1.6% increase given in IEA's WEO 2006. The largest difference between the two is for China: IEA's projection for this country is nearly 2 percentage points lower than in the IEO2006 Reference case. Also, by fuels, IEA projects somewhat higher growth for oil and renewable energy demand than does IEO2006, but much lower growth for coal and nuclear power consumption.

### Figure 4

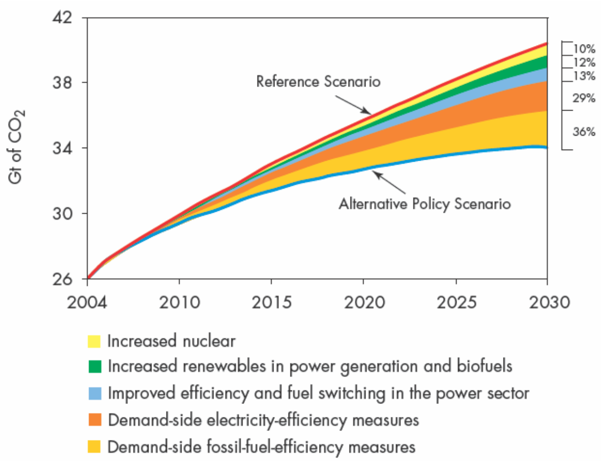
**Potential change in energy-related CO2 emissions 2004-2030**




Source: World Energy Outlook 2006. IEA, 2006

### Figure 5

**Potential Global Savings in CO2 emissions 2004-2030**




Source: World Energy Outlook 2006. IEA, 2006

*Policy Scenario* fully pay for themselves since the associated costs are lower than investments required to meeting higher energy demand. For example, an additional dollar invested in more efficient electrical equipment and appliances avoids more than USD 2 in investment on building additional generating capacity (this ratio is even higher in non-OECD countries). Also, in the transport sector, the value of fuel savings due to more efficient new vehicles more than doubles the additional capital expenditure.

Although overall investment is lower than in the Reference Scenario, investment gets far more concentrated on the demand-side than in the supply-side, thereby increasing the number of individual investors. Even though the average payback period of demand-side investments is very short (typically less than 3 to 5 years), this still represents a significant barrier to investments in end-use energy efficiency because individual consumers are not usually aware of the potential benefits of energy conservation and because some of them face severe financial constraints.

## Beyond 2030: IEA's Accelerated Technology Scenarios to 2050

Although encouraging, IEA's *Alternative Policy Scenario* to 2030 will not move the world onto a fully sustainable path. It is based on currently enacted or proposed measures and so it does not reflect the ultimate technical or economic potential for energy efficiency and $CO_2$ emissions reduction. In fact, bigger savings are possible with enhanced penetration of existing advanced technologies and accelerated introduction of additional new technologies which have not yet been tried on a commercial basis, but which are expected to be so by 2030. With the correct policy measures and the full commitment of energy producers and consumers, these efforts could bring the world onto a much more sustainable energy path by 2050.

Even if we factor in all the uncertainties when looking too far ahead, the IEA has managed to do fairly detailed estimates of the potential for savings of these measures to the horizon of 2050.

The study[5] departs from a *Baseline Scenario for 2050* which results from extending WEO's *Reference Scenario* for 2030 and adding the effects of technology developments and improvements in energy efficiency and decarbonisation that can be expected by 2050 on the basis of government policies already enacted.[6] Then, it computes the potential gains that could be reached in terms of reduced energy demand and $CO_2$ emissions by comparing Baseline forecasts to five different "*Accelerated Technology Scenarios*" (ACT). These ACT scenarios combine technologies and best practices which already exist, or which are likely to become commercially available by 2030. They concentrate on four main technological areas:

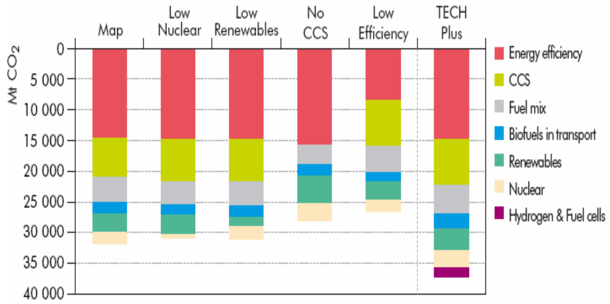
1. Enhanced energy efficiency
2. Increased role of renewables

[5] Energy Technology Perspectives 2006. IEA 2006

[6] These policies will have an effect beyond 2030 because of the long lifetime of much of the energy-using capital stock. For example, the lifespan for power plants is typically 25 to 40 years and that for buildings can exceed 60 years.

**Figure 6**

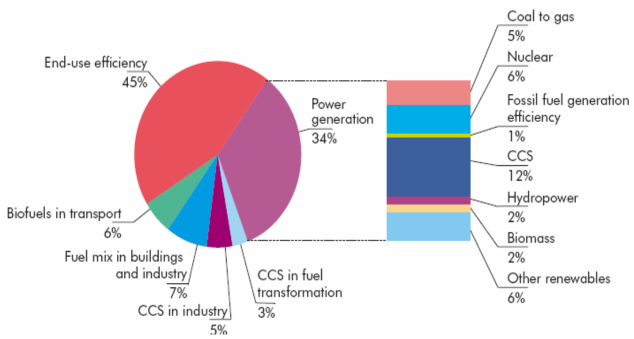
**Emissions reduction by contributing factor (with respect to Baseline Scenario in 2050)**




Source: Energy Technology Perspectives 2006. IEA, Nov 2006

**Figure 7**

**Emissions reduction in the MAP Scenario by technology area (%reduction below Baseline 2050)**




Source: Energy Technology Perspectives 2006. IEA, Nov 2006

3. Increased role of nuclear
4. Deployment of clean coal technologies (CCS)[7]

The benchmark ACT scenario is the *MAP ATC Scenario*, which makes fairly optimistic assumptions regarding all four technological areas. Besides the MAP scenario, four alternative ACT scenarios are considered, which explore the impact of less effective policies in each of these four areas. By comparing each of these four ACT scenarios to the MAP scenario one gets an idea of the importance of each particular technological area in curbing energy demand and emissions. [8]

As can be seen, energy demand can be substantially reduced below its baseline level (24%) and global $CO_2$ energy-related emissions could be capped at today's levels by 2050. Under the MAP scenario, demand for electricity is reduced by 30% with respect to the baseline, 20% that for oil, 30% that for gas and 60% that for coal.

The main results obtained with this simulation are shown in figures 6 to 11. These substantial gains are grounded in:

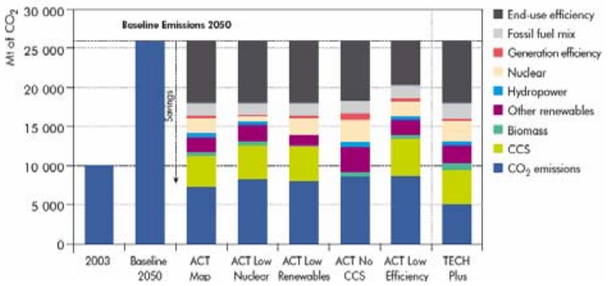
1. Energy efficiency gains in transport, industry and building sectors
2. Decarbonisation of power generation as the power mix shifts towards nuclear, renewables, natural gas and clean coal
3. Increased use of biofuels for road transport

As expected, the biggest contributing area overall is energy efficiency, which, under the MAP Scenario, contributes more than 50% of emission reductions with respect to the Baseline Scenario (adding increases in efficiency in end use sectors and in fossil fuel power generation as well as fuel switching, which is also a source for enhanced energy efficiency. See figure 9). Moreover, improved energy efficiency in buildings, industry and transport sectors leads to between 17% and 33% lower energy use than in the Baseline Scenario by 2050.

All in all, energy intensity gains increase in all ACT scenarios with respect to the Baseline scenario (and also historical records). Under the MAP scenario, energy intensity could decline by 2% per year on average. As in the 2030 horizon analysis, potential improvements to the horizon of 2050 are significantly bigger in developing and transition economies (See figures 10 and 11).

**Figure 8**

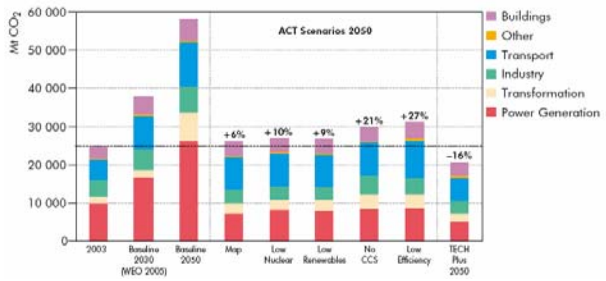
**Emissions reduction in the power sector by technology area**




Source: Energy Technology Perspectives 2006. IEA, 2006.

**Figure 9**

**Global CO2 emissions in the Baseline Scenario, ACT scenarios and TECH Plus Scenario**




Source: Energy Technology Perspectives 2006. IEA, Nov 2006

[7] The adoption of CCS technologies remains minimal in the Baseline Scenario.
[8] A sixth scenario, the TECH Plus Scenario, is included which makes more optimistic assumptions than the MAP about the progress of promising energy technologies. In particular, it assumes much lower costs for R&D, technology development and learning by doing of fuel cells, renewable electricity technologies, biofuels and nuclear technologies. All ACT scenarios and the TECH Plus scenario are based on the same macroeconomic assumptions as in the Baseline Scenario. World GDP is assumed to grow on average at 2,9% annually until 2050 and per capita incomes by 2%.

## Conclusions

Under current energy trends, the world will follow an unsustainable path through to 2030. According to the great majority of official forecasts, primary energy demand could increase by over 50% between now and 2030, causing global greenhouse gas emissions (GHG) to rise by more than 30%. Besides putting high pressure on energy supply, this is clearly not compatible with a needed 10% cut in GHG emissions by 2030 in order to be on track for stabilisation of atmospheric concentrations by 2050.

But these projections are not set in stone. Things can (and must) change thanks to the implementation of adequate policy and market measures.

Curbing energy demand through enhanced energy efficiency is the cheapest and quickest alternative to tackle the problem but diversifying and decarbonising supply will clearly be a must too. This note has concentrated on the analysis of the potential foe improvements in energy efficiency as a driver for changes in the current energy paradigm toward a higher sustainable model. The next one in this series will analyse the potential for energy supply measures to reduce fossil dependence and CO2 emissions.

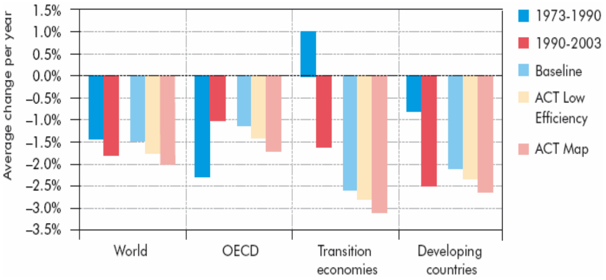
As shown, under currently enacted or proposed measures, the world could reduce its primary energy demand by roughly China's today consumption with respect to forecasts given in the Reference Scenario, its oil demand in more than Saudi Arabia's current annual production and its energy-related $CO_2$ emissions by half of today's OECD emissions. Energy efficiency improvements contribute more than two thirds of these savings, especially in non-OECD countries, where potential for energy efficiency improvements in power generation and end-uses is higher.

Although these savings are not enough to move the world onto a fully sustainable path, they still provide a good start. Moreover, higher conservation is even possible in 2050 on the ground of fairly realistic assumptions about technology and policy developments. Energy demand could be reduced by a quarter with respect to the baseline and $CO_2$ emissions could be capped to today's values.

Energy efficiency will contribute more than half of these savings, showing, once again, that it provides the most economic and effective alternative to tackling the challenge of ensuring energy security at affordable prices and curbing carbon emissions.

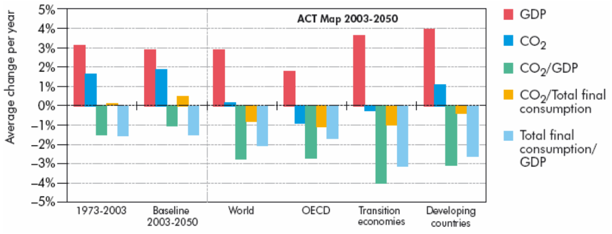
### Figure 10

**Changes in final energy intensity, by region**




### Figure 11

**Growth in GDP and emissions and energy intensity, by region**




Source: Energy Technology Perspectives 2006. IEA, 2006.

## Appendix: shedding some light to the question of energy intensity and efficiency

The main long term drivers for energy demand are economic growth and **energy intensity**, which measures the amount of energy that an economy needs to consume in order to produce one unit of output.

Energy intensity varies significantly across countries. It depends on factors such as economic structure (industry tends to be more energy intensive than services), per capita income (higher incomes are associated to higher per capita energy use), fuel mix (electricity and gas are more efficient than coal, fuel oil or traditional biomass), relative prices and technology efficiency standards. In general, least developed economies tend to present much lower energy intensities than developed ones because they have a small degree of industrialization and low rates of accessibility to modern energies by their population. On the other hand, developing and transition economies tend to be more energy intensive than developed ones due to a low degree of tertiarization, inefficient fuel mixes, big energy subsidies and lower efficiency standards.

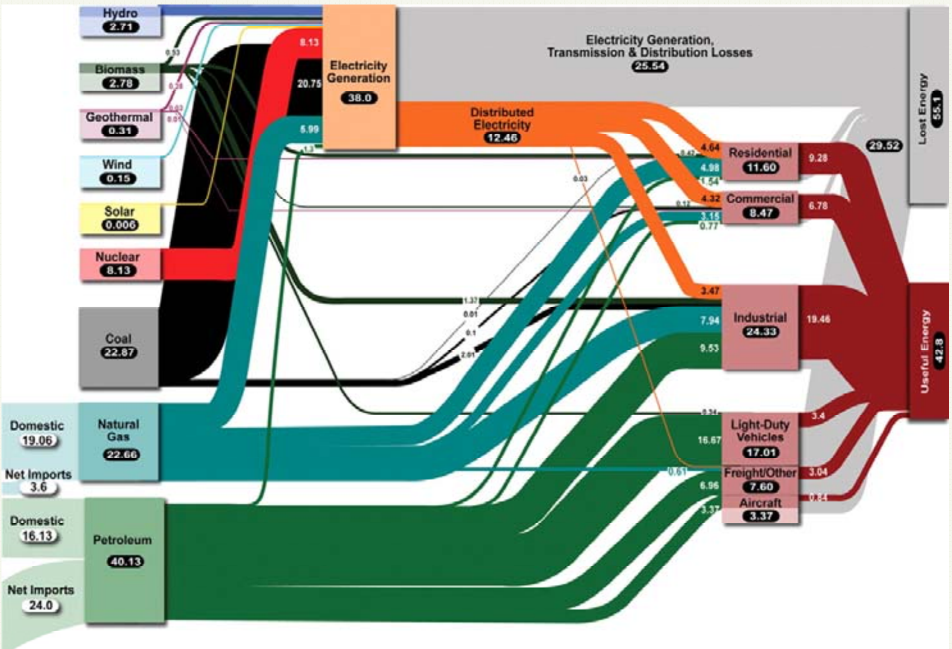
Improvements (i.e., declines) in energy intensity provide the least cost alternative to decouple energy demand and CO2 emissions from economic growth. Economies can basically improve their energy intensity in two ways:

1. By changing the composition of their economic structure towards high value added - less energy intensive sectors.
2. By improving their **energy efficiency**:

- Increase rate of conversion in energy transformation (power generation and oil refining)
- Increase efficiency standards in the use of energy in the industrial processes, transportation and residential and commercial sectors
- Changing the mix of fuel towards a higher use of more efficient fuels (for example, substituting traditional biomass for modern energies, coal or oil for natural gas or electricity in the industry, etc)

The following flow chart illustrates the complex energy flows of a developed economy (in this case, the US one) and how current energy conversion routes are far from their theoretical efficiency limits: for example, with the present mix of fuels, electricity production is less than 40% efficient.

**The complex system of energy flows: the example of the USA**




Source: G. M. Whitesides et al., Science 315, 796 -798 (2007), from Lawrence Livermore nacional Laboratory, University of California

Starting to the left-hand-side, the graph starts by distributing the different flows of primary energy used by the US economy (nuclear, coal, oil, natural gas, hydro and other renewables) into their alternative uses: as a fuel and raw material in electricity generation, as a fuel or raw material in the industry, as a fuel for residential and commercial purposes, and as a fuel in transportation. As can be seen, at the end of the day, the amount of useful (or final) energy delivered is considerably lower than the primary energy used to produce it (60% of the primary energy used is lost throughout the whole process). This is mainly due to low energy conversion ratios and high transportation losses in the power sector and in the use of oil for transport. Both sectors provide a big potential for energy efficiency improvements in developing countries and further improvements are also possible in the developed world provided that technology advances are made in the right direction.