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TECHNOLOGY PENETRATION AND CAPITAL STOCK TURNOVER: LESSONS FROM IEA SCENARIO ANALYSIS

Cédric Philibert, IEA
May 2007

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The ideas expressed in this paper are those of the authors and do not necessarily represent views of the OECD, the IEA, or their member countries, or the endorsement of any approach described herein.

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FOREWORD

This document was prepared by the OECD and IEA Secretariats in April-May 2007 in response to the Annex I Expert Group on the United Nations Framework Convention on Climate Change (UNFCCC). The Annex I Expert Group oversees development of analytical papers for the purpose of providing useful and timely input to the climate change negotiations. These papers may also be useful to national policy-makers and other decision-makers. In a collaborative effort, authors work with the Annex I Expert Group to develop these papers. However, the papers do not necessarily represent the views of the OECD or the IEA, nor are they intended to prejudge the views of countries participating in the Annex I Expert Group. Rather, they are Secretariat information papers intended to inform Member countries, as well as the UNFCCC audience.

The Annex I Parties or countries referred to in this document are those listed in Annex I of the UNFCCC (as amended at the 3rd Conference of the Parties in December 1997): Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, the European Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America. Korea and Mexico, as OECD member countries, also participate in the Annex I Expert Group. Where this document refers to “countries” or “governments”, it is also intended to include “regional economic organisations”, if appropriate.

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Executive Summary

The aim of this paper is to reflect on the significant differences between the emissions reductions projections in mid-term and long-term scenarios, and to explore their policy implications. It draws mainly on two recent IEA publications: the 2006 *World Energy Outlook* (WEO), which contains energy and energy-related CO₂ projections up to 2030, and the 2006-published *Energy Technology Perspectives* (ETP), which considers scenarios and strategies up to 2050.

The 2006 WEO Alternative Policy Scenario (APS) illustrates what would happen if the policies and measures that countries are currently only considering are adopted and implemented. More than 1400 such policies are considered in the analysis, in both industrialised and developing countries. Under this scenario, global energy-related CO₂ emissions would be reduced by 16 % in 2030 in comparison with the 2006 WEO Reference Scenario, that is, 31 % above 2004 levels instead of 55 % in the Reference.

The ETP Accelerated Technology (ACT) scenarios focus on technologies that exist today or are likely to become commercially available in the next one to two decades. The increased uptake of cleaner and more efficient energy technologies is driven by various policies, from support to research and development (R&D) to demonstration programmes to policy instruments. Moreover, the ACT scenarios are based on a CO₂ reduction incentive being in place by 2030 in all countries. In the ACT scenarios, global energy-related CO₂ emissions initially rise, then peak and almost return to approximately current levels by 2050.

While a direct comparison of the models and their results would be complicated, one of the reasons for the larger emission reduction potential in 2050 is the longer time horizon, allowing greater penetration of cleaner and more efficient technologies. The development of new technologies requires time. Capital stock turnover slows their dissemination. The rate of introduction of climate-friendly technologies in the marketplace, without premature capital scrapping, is limited to the rate of capital stock turnover, if emission reductions are to remain affordable. Many policies aimed at fostering technology improvements and speeding the dissemination of cleaner and more efficient technologies will have little effect in their first years or even decades but have significant effects in the longer term.

The following four policy conclusions drawn from this scenario analysis are suggested for discussion:

1. Important changes beyond 2030 require important efforts before 2030

Because capital stock turnover is slow and the lead time for the development of new technologies is long, policies to stimulate such changes should be introduced as soon as possible. If new policies are not introduced before 2030, the subsequent emission pathway could still be curved downward, but the peak would be further away and the reduction in a given year much lower.

2. Long-term price/policy signals are required

Developers of new technologies and investors in new capital stock must be given robust long term signals to develop the appropriate technologies, invest in them and benefit from learning-by-doing cost reductions that can make them competitive in the marketplace (taking a carbon price into account).

3. Short term emissions targets may not drive all necessary action

Short term emissions targets may not suffice to induce the kind of R&D efforts and investments that would command modest short term but significant long term change in emissions.

4. Developing countries offer significant opportunities – and challenges

Developing countries are investing in a considerable amount of new energy infrastructure and energy-intensive equipment at a rapid rate to satisfy growing economies and population. This presents a considerable challenge for climate change policy, with a risk of “locking-in” to high-emissions pathways. Conversely, the

rapid pace of development also offers great opportunities to introduce a combination of climate-friendly technologies when this is the least cost option.

1. Introduction

The aim of this paper is to reflect on the significant differences between the emissions reductions projections in mid-term and long-term scenarios, and to explore their policy implications. It draws mainly on two recent IEA publications: the 2006 *World Energy Outlook* (WEO), which contains energy and energy-related CO₂ projections up to 2030, and the 2006-published *Energy Technology Perspectives* (ETP), which considers scenarios and strategies up to 2050. The analysis focuses on a comparison of the Alternative Policy Scenario of the 2006 WEO, and the various Accelerated Technology (ACT) Scenarios in the ETP.

The next section provides the necessary background on these two publications and their energy-related CO₂ emissions by 2030 and 2050, respectively. The third section investigates in some more depth the reasons for the large differences in the amount of emission reductions at these dates. Capital stock turnover and technology maturation lead times, in particular, are identified as primary reasons for the differences.

The fourth section suggests several possible policy conclusions that can be drawn from this analysis. They include thought pieces with respect to the action required in the short-term; to the necessity of long-term signals; to the advantages and limitations of short-term targets; and to the opportunities and challenges the international community faces with respect to emission reductions in developing countries.

2. The WEO-APS and the ETP-ACT scenarios

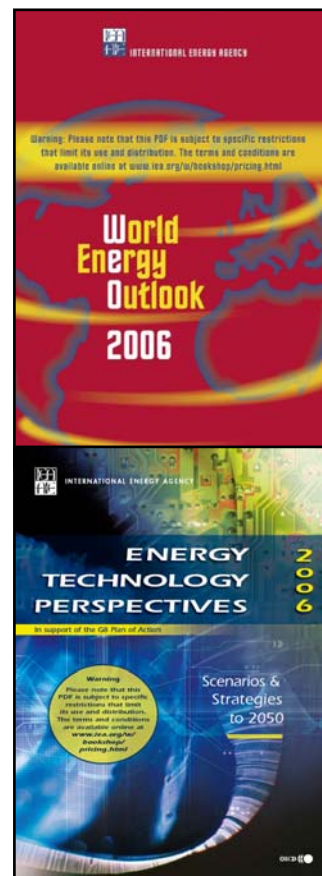
2.1 The 2006 World Energy Outlook

The 2006 World Energy Outlook (IEA 2006a) offers two main scenarios to 2030 – the Reference Scenario and the Alternative Policy Scenario. Both are briefly described in this section.

2.1.1 The Reference Scenario

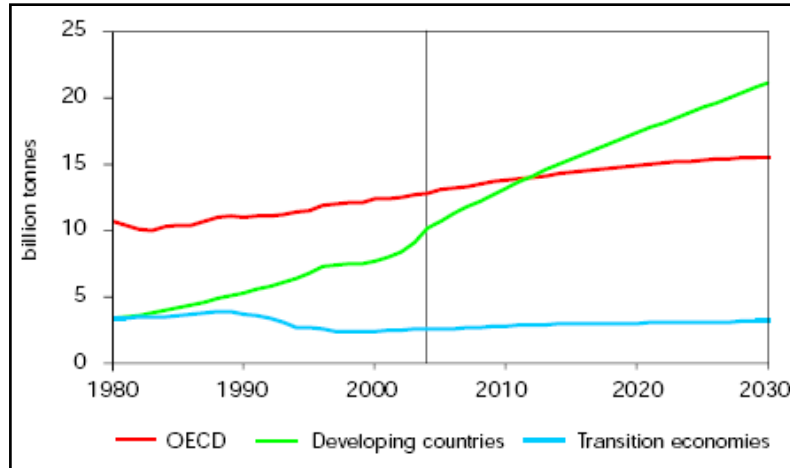
The “Reference scenario” takes account of those government policies and measures that were enacted or adopted by mid-2006, though many of them have not yet been fully implemented. Other important assumptions are made on demographic growth (at 1% per year on average), and economic growth. While the latter would average 3.4% per year over the projection period, it is neither constant nor evenly distributed. The global economy is assumed to grow at 4% over 2004-2015, then 2.9% in 2015-2030. China, India and other Asian developing countries are expected to grow faster than other regions. While growing at a slower pace than in transition and developing economies, per-capita income in OECD countries would still be almost four times the average for the rest of the world in 2030.

In the Reference Scenario, the global energy demand would increase by 53% between 2004 and 2030 – an average annual rate of 1.6%, mostly (70%) fuelled by the energy thirst of developing countries. Fossil fuels



would remain the dominant source of energy, accounting for 83% of the overall increase in demand. While the share of oil would drop, gas and, moreover, coal, would increase their shares.

Figure 1: Energy-related CO₂ emissions by region (Reference)

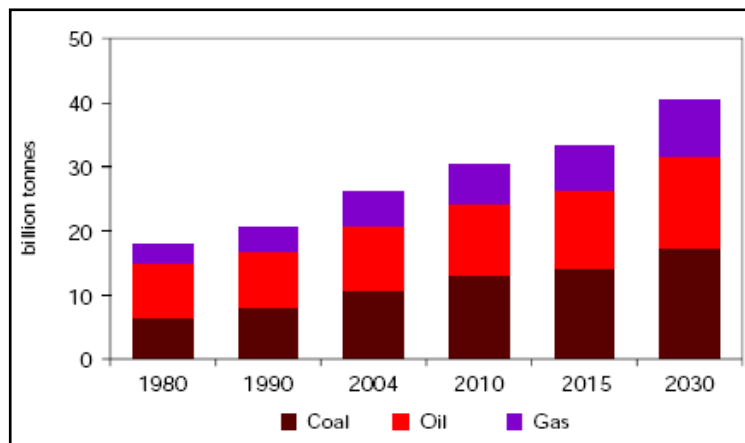


Source: WEO 2006, Figure 2.9, p.82. Excludes emissions from international marine bunkers

As a consequence, global energy-related CO₂ emissions increase by 55% over the projection period (Figure 1), slightly faster (1.7% per year) than primary energy use, as the fuel mix becomes slightly more carbon-intensive. Global CO₂ emissions would thus reach 40.4 billion tonnes in 2030. China alone accounts for 39% of the increase, and overtakes the United States as the world's biggest emitter before 2010, well before previously forecasted. As a whole, developing countries CO₂ emissions overtake OECD countries between 2010 and 2015.

The power sector alone contributes almost half (47%) of the increase in emissions, and transport a fifth. Amongst all fuels coal becomes the leading contributor to global emissions, as shown in Figure 2.

Figure 2: World energy-related CO₂ emissions by fuel (Reference scenario)



Source: WEO 2006, Figure 2.8, p.81

By 2010, energy-related CO₂ emissions would be 48% higher than in 1990. If all greenhouse gas emissions rise at the same rate as energy-related emissions, Annex I in aggregate would not be able to meet the overall emissions-reduction target of the Kyoto Protocol on current trends. The emissions of Annex I OECD countries would be 29% above the target – 19% excluding the United States and Australia. The emissions of Annex I transition economies would be 22% below target, but this would not be enough to make up the entire gap given their relatively small share of global emissions.

2.1.2 The Alternative Policy Scenario

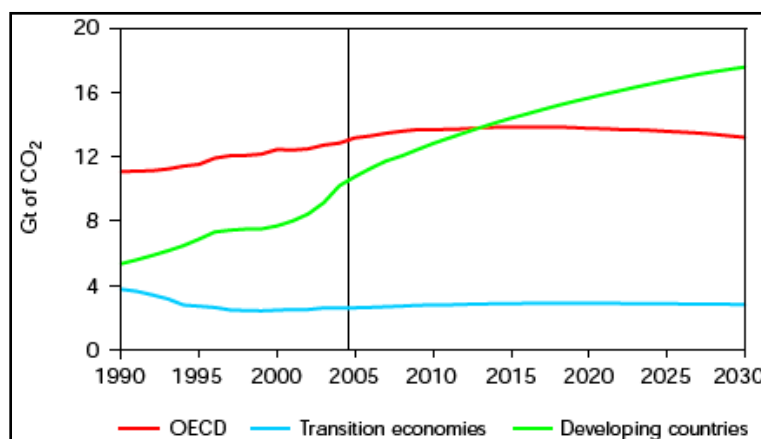
The Alternative Policy Scenario (APS) uses the same demographic and economic assumptions as the Reference Scenario. The former, however, is designed to illustrate what would happen if the policies and measures that countries are currently only considering are adopted and implemented. More than 1400 such policies are considered in the analysis, in both industrialised and developing countries, regarding in particular renewables and nuclear power, and energy efficiency or emissions of all consuming sectors. It must be noted that no country is assumed to adopt policies that it does not have under consideration, even though they may be under consideration elsewhere.

Not all these policies would mainly aim at reducing energy-related CO₂ emissions; many primarily or equally aim at strengthening energy security in response to a series of supply disruption, geopolitical tensions and surging energy prices that occurred over the past two years. To give one-only example of such policies, the APS assumes, contrary to the Reference scenario, that the Corporate Average Fuel Economy standards are reformed following the proposal made by the National Highway Traffic Safety Administration, and that the emissions standards proposed by the California Air Resource Board for light-duty vehicle are introduced in California.

These policies are expected to result in the faster deployment of cleaner and more efficient energy technologies. Although most technological advances will be made in OECD countries, non-OECD countries will be able to benefit from them. As a result, global energy intensity falls more rapidly in this scenario than in the reference scenario.

Following the APS, the world primary energy demand in 2030 is about 10% lower than in the Reference Scenario (and already 4% lower in 2015). Global energy-related CO₂ emissions would be reduced by 16% with respect to the Reference – that is, 31% above 2004 levels instead of 55% in the Reference. As shown on Figure 3, emissions from OECD countries would peak around 2015 then recess before 2030, where they almost return to their 2004 levels.

Figure 3: Energy-related CO₂ emissions by Region (Alternative Policy Scenario)



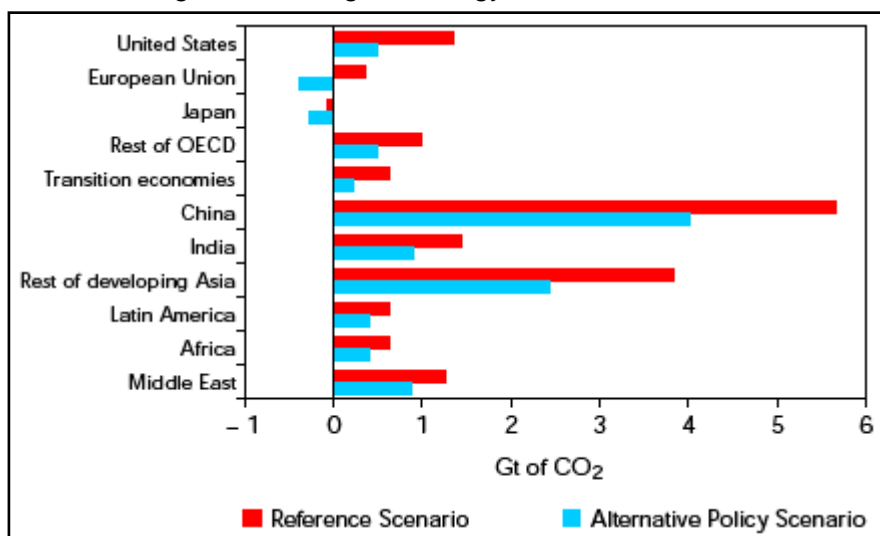
Source: WEO 2006, Figure 7.11, p.189

As shown on Figure 4, Europe and the Pacific regions are responsible for the decline in emissions after 2015, with emissions lower in 2030 than today. In non-OECD countries energy-related CO₂ emissions continue to grow but at a slower pace than in the Reference, up from 10.2 Gt in 2004 to 17.5 Gt in 2030 – against 21.1 Gt in the Reference. Chinese emissions rise by 4 Gt, accounting for half of the global increase, instead of almost 6 Gt in the Reference – thus also showing the greatest emission reductions in the APS relative to the Reference.

End-use energy efficiency improvements account in 2030 for about two-third of the overall emissions reductions with respect to the Reference: fuel savings account for 36% through more efficient vehicles, industrial processes and heating applications, while lower electricity demand, from more efficient appliances, industrial motors and buildings, represents 29%. Fuel switching, mainly from coal to gas, and improved supply-side efficiency, account for 13%, increased use of renewables, mainly in power generation and transport (biofuels) for 12%, and increased reliance on nuclear power for 10%.

Meeting energy demand requires less investment in the Alternative Policy Scenario than in the Reference Scenario. Consumers spend USD 2.4 trillion more in more efficient devices, reducing energy supply investment needs by USD 3 trillion. Consumers see (undiscounted) savings in their energy bills of USD 8.1 trillion, comfortably offsetting their increase end-use investments. It is worth noting that this estimate rests on the assumption that, despite a lower demand, oil prices are the same in both scenarios, as the economic feedbacks of energy demand reduction are not modelled.

Figure 4: Change in energy-related CO₂ emissions



Source: WEO 2006, Figure 7.12, p.189

Nevertheless, the projected energy savings and reductions in CO₂ emissions considered in the APS do not reflect the ultimate technical or economic potential. The 2006 WEO also include a so-called “Beyond Alternative Policy Scenario” showing what would be necessary to bring emissions in 2030 back to 2004 levels (such as an early but massive introduction of carbon dioxide capture and storage, new energy efficiency improvements, more renewable and nuclear). According to the WEO, “*Technologies exist today that could permit such radical changes over the Outlook period, but there are many barriers to their deployment, including the following:*

- *The life span of the existing capital stock limits commercial opportunities for new plant construction – particularly in OECD countries.*
- *Even existing highly-efficient technologies have yet to be widely adopted.*
- *The costs are, in some cases, likely to be considerably higher than those of established technologies.”*

In sum, the technology shifts outlined in the BAPS Case would represent “*a very severe challenge in terms of their speed of deployment.*” On a more positive note, the WEO also notes that while the primary goal would be to mitigate climate change, “*Lower oil and gas demand and imports in developing countries (associated with the BAPS scenario) would boost the disposable incomes of households and businesses and the potential for more rapid economic and human development. Recognition of the mutual energy-security*

benefits of such policies would facilitate the establishment of co-operative arrangements between developing and OECD countries.”

2.2 The Energy Technology Perspectives

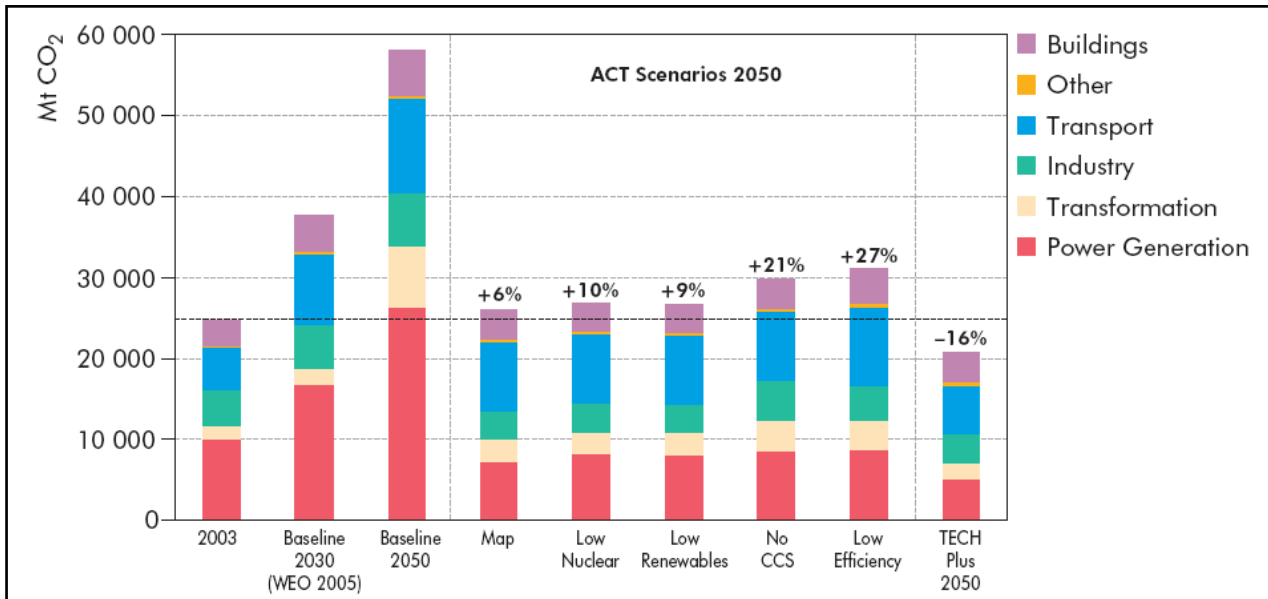
The Energy Technology Perspectives (IEA, 2006b) offers various scenarios to 2050. The Baseline scenario extends the WEO 2005 Reference Scenario from 2030 to 2050. Five different Accelerated Technology scenarios (ACT scenarios) investigate the potential of energy technologies and best practices aimed at reducing energy demand and emissions. In addition, a more optimistic TECH Plus scenario assumes faster technical progress. The global energy-related CO₂ emissions resulting from these various scenarios are all shown on Figure 5.

2.2.1 The Baseline Scenario

As in the WEO Reference Scenario (IEA, 2005), the ETP Baseline includes the effects of technology developments and improvements in energy efficiency that can be expected on the basis of government policies already enacted. Many of these policies will have an effect beyond the 2030 timeframe because of the long lifetime of much of the energy-using capital stock. Rising oil and gas prices will also affect technology development beyond 2030.

World economic growth in the scenarios is a robust 2.9% per year between 2003 and 2050, with per capita income growth of 2% on average, ranging from 1% per year in the Middle East to 4.3% in China. Despite efficiency improvement, overall energy uses in the Baseline Scenario more than double between now and 2050. The carbon intensity of the world's economy increases due to greater reliance on coal for power generation and the increased use of coal in the production of liquid transport fuels. Coal demand in 2050 is almost 3 times higher than today, gas demand increases by 138% and oil demand by 65%. As a result, energy-related CO₂ emissions rise by 137%, from 24.5 Gt in 2003 to 58 Gt in 2050.

The energy-related CO₂ emissions by 2050 are closer to the total CO₂ emissions by the same date in the IPCC SRES Scenario “A1B” (IPCC, 2001, p.100). The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1B Scenario is based on a “balance across all energy sources”, on the assumption that similar improvement rates apply to all energy supply and end use technologies, and, like other IPCC scenarios, “*does not explicitly assume implementation of the UNFCCC or the emissions targets of the Kyoto Protocol*”. Emissions resulting from the continuation of the A1B scenario up to 2100 have been associated with a best estimate of a warming of 2.8°C and a likely range 1.7 to 4.4°C by 2100 (IPCC, 2007a).

Figure 5: Global Energy-Related CO₂ emissions by 2050 in the various ETP scenarios

Source: ETP, Figure 2.1, p.46

2.2.2 The ACT and TECH Plus Scenarios

The five Accelerated Technology (ACT) Scenarios and the TECH Plus Scenario are all based on the same macro-economic assumptions as in the Baseline Scenario. The underlying demand for energy services is also the same – countries are not asked to reduce their aspirations for more energy services in these scenarios. Thus, these scenarios do not analyse any possibility of reducing the demand for energy services, such as restricting personal travel activity. Instead, they investigate the potential of energy technologies and best practices aimed at reducing energy demand and emissions, and diversifying energy sources.

The ACT scenarios focus on technologies which exist today or are likely to become commercially available in the next one to two decades. The increased uptake of cleaner and more efficient energy technologies are driven by the various policies, from R&D support to demonstration and deployment programmes to policy instruments to overcome barriers. Moreover, the ACT scenarios are based on CO₂ reduction incentives being in place from 2030 in all countries. These incentives could take many forms, from an emissions trading scheme, pricing formulas, regulations etc, but would lead to the adoption of low carbon technologies with a cost of up to USD 25 per tonne of CO₂ avoided. A value of USD 25 per tonne of CO₂ would add about USD 0.02 per kWh to the cost of coal-fired electricity and about USD 0.07 per litre to the cost of gasoline. Such value is somewhat arbitrary and is given for illustrative purposes only. According to the IPCC (2007b) “peer-reviewed estimates of the social cost of carbon for 2005 have an average value of US\$ 12 per tonne of carbon dioxide but the range around this mean is large. For example, in a survey of 100 estimates, the values ran from US\$ 3 per tonne of carbon dioxide up to US\$ 130 per tonne of carbon dioxide”.

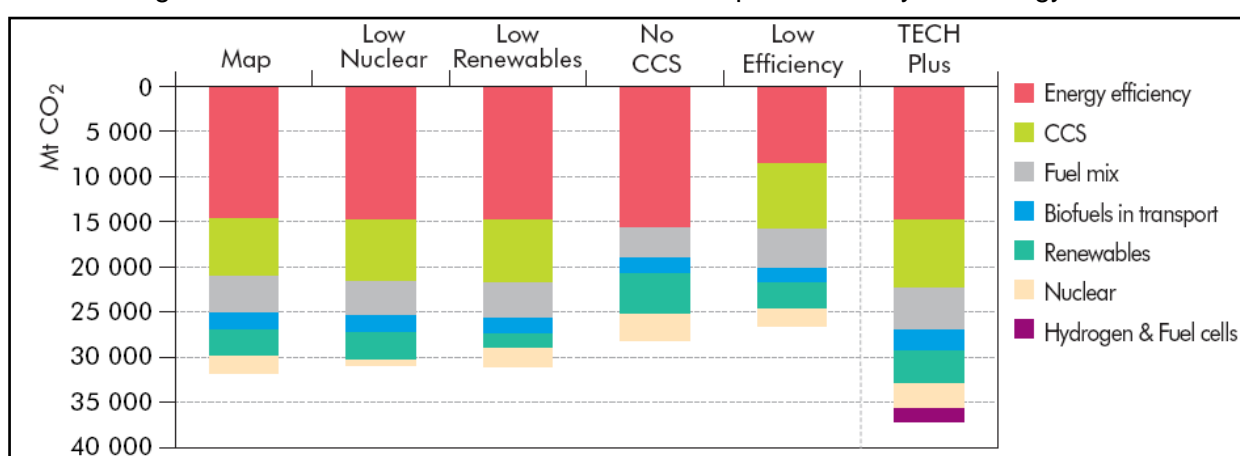
The ACT scenarios vary in that they assume different rates of progress in key areas such as renewable power generation, nuclear power, CO₂ capture and storage (CCS), and end-use efficient technologies. They are the following:

- The *ACT Map Scenario* is relatively optimistic in all these technology areas. In particular, barriers to CCS are overcome, with costs reduced to USD 25/t CO₂ or less; cost reductions for renewable energy continue with increased deployment through learning effects; expansion of nuclear capacity occurs where it is economic to reduce CO₂ emissions and is acceptable; and progress in energy efficiency is accelerated as a result of successful policies. The other ACT scenarios are mapped against the results of this scenario.

- The *Act Low Renewable Scenario* assumes slower cost reductions for wind and solar.
- The *Act Low Nuclear Scenario* reflects the limited growth potential of nuclear if public acceptance remains low, nuclear waste non-proliferation issues remain significant.
- The *Act No CCS Scenario* assumes that the technological issues facing CCS remain unsolved.
- The *Act Low Efficiency Scenario* assumes less effective energy-efficiency policies.

The TECH Plus Scenario is built on even more optimistic assumptions on technology improvements, while retaining the same CO₂ reduction incentive and level of policy efforts as in the ACT Scenarios. It assumes in particular greater cost reductions and technological improvements for fuel cells, renewable electricity generation technologies, biofuels and nuclear technologies.

Figure 6: reduction in CO₂ emissions in the Map Scenario by technology area



Source: ETP, figure 2.3, p.48

In the ACT Map scenario, global emissions initially rise, then peak and almost return to current levels by 2050, being only 6% higher than in 2003. As shown on Figure 6, energy efficiency improvements in the end-use sectors are the single largest contributor to CO₂ emission reductions, contributing 45% of the overall emission reduction. The use of CO₂ capture and storage accounts for 20% of the CO₂ savings, in the power generation but also industry and in fuel transformation, including coal-to-liquid plants. Renewable ranks third with 16% thanks to biofuels in transport, biomass, hydropower and others in power generation¹, fuel switching from coal to gas in power generation, industry and buildings ranks fourth with 12%, nuclear power fifth with 6% and fossil fuel power generation efficiency accounts for the remaining 1%. *A contrario* the four variants lead to higher emissions levels than in the Map Scenario as progress are slower either on efficiency or nuclear or renewables, or if CCS cannot be introduced. This shows that slower progress in these areas will lead to higher emissions or increase the cost of a given emission reduction target, it also highlights that there is no silver bullet; a portfolio of technologies is needed. Nevertheless, all ACT scenarios would lead by 2050 to lower energy-related CO₂ emission levels than the lowest overall CO₂ emission level of the IPCC SRES scenarios (IPCC, 2001, p.100).

Global emissions in 2050 are 55% lower in the Map Scenario than in the Baseline Scenario. This cannot but affect all regions of the World: CO₂ emissions in the OCED are 60% lower, in transition economies 42% lower, and in developing countries 54% lower. By comparison with 2003 levels, emissions are in the Map Scenario 32% lower in the OECD, 10% lower in transition economies, but still 65% greater in developing countries. This compares with respective increases of 69%, 55% and 256% in the Reference Scenario.

¹ A greater use of solar heat is also included in the energy efficiency improvements, mostly in buildings.

Energy prices in each of these scenarios respond to changes in demand and supply. In the Baseline Scenario the crude oil price increases from USD 39/bbl to about USD 60/bbl in 2050. The reduced demand in the ACT scenarios lowers the crude oil price by between USD 15 per barrel in 2050; the net effect on consumer prices and the risks of “rebound effects” (i.e. greater demands for energy services due to their lower costs) are limited, as the CO₂ emission reduction incentive of USD 25/t CO₂ translates into about USD 10/bbl.

Not accounting for public and private R&D expenses, but accounting for the costs of deployment programmes, the net investment needs for electricity supply (discounted back to 2003) would be USD 300 billion lower in the Map Scenario than in the Baseline, as reductions in fossil fuel plants and transport and distribution networks investment needs due to higher end-use efficiency would more than cover increases in investments in renewable, nuclear and CCS. However, demand-side investments would be about USD 1.8 trillion higher, while discounted fuel savings would amount to USD 1.4 trillion from these investments. There is therefore little difference in the costs between the MAP and Baseline scenarios, but the costs, in particular investment costs, would be shifted from electric utilities to consumers. The average cost of CO₂ reduction would be much lower than its marginal cost set illustratively at USD 25/t CO₂, as many of the emissions reduction options have low or even negative costs. What appear economically sensible may, however, prove politically difficult as it shifts the burden to individuals.

3. Lessons from IEA scenario analysis

The WEO APS examines only those policies under consideration by governments as of mid-2006. It plays a very valuable role in signalling to governments the global potential to reduce CO₂ emissions of the policies they are currently considering. The Energy Technology Perspectives ACT and TECH Plus scenarios go further than this and illustrate the potential contribution of existing technologies and those that will be commercialised in the next one to two decades.

Energy-related emissions by 2030 in the APS would be 16% lower than in the Reference Scenario and in the ACT Map Scenario 55% lower by 2050 than in the Baseline Scenario. This comparison suggests that there would be more flexibility to reduce emissions after 2030 than before that date. Beyond possible differences in modelling assumptions, two main reasons can be suggested to explain the large differences in emission reduction potential between 2030 and 2050.

3.1 Differences in modelling assumptions

The Reference Scenario of the 2006 WEO is an update of previous modelling exercises in the 2004 and 2005 WEO; the Baseline Scenario is an extension of the Reference Scenario of the 2005 WEO. But there are significant differences in the construction of the APS and ACT Scenarios. The first is based on policies and measures under consideration; the second is based on assumptions relative to technical improvements, including the pace of their development and the speed of their dissemination. Arguably, however, the measures considered in the WEO APS would also affect the pace of the development and dissemination of technical improvements.

Another important factor of course in the ETP is the introduction of a homogenous incentive at the illustrative level of USD 25/t CO₂ throughout the world by 2030 – including in developing countries. However, the WEO APS scenarios include policies and measures that have effects similar to a CO₂ reduction incentive. Some would take the form of rather direct financial incentives; indeed, such incentives are even part of the Reference and Baseline Scenarios since they have already been put in place by various governments or other (e.g. State) authorities, as carbon taxes, emissions trading schemes or feed-in tariffs and renewable energy portfolios, to name only some of the most significant.

Moreover, while the WEO APS appears to entail small overall costs to the economy, if any, the overall costs implied by the ACT scenarios seems rather limited as well, and for the same fundamental reasons: fuel

economies pay for costlier emission reduction options. Hence, the assumption of an incentive driving marginal abatement costs up to USD 25 per tonne CO₂, although important it is, is not the only difference between the APS and ACT scenarios.

Hence, while it can be misleading to compare the WEO APS emission reductions in 2030 with the ETP ACT reductions in 2050, one of the reasons for the larger emission reduction potential in 2050 is the longer time horizon allowing greater penetration of cleaner and more efficient technologies.

3.2 The development of new technologies requires time

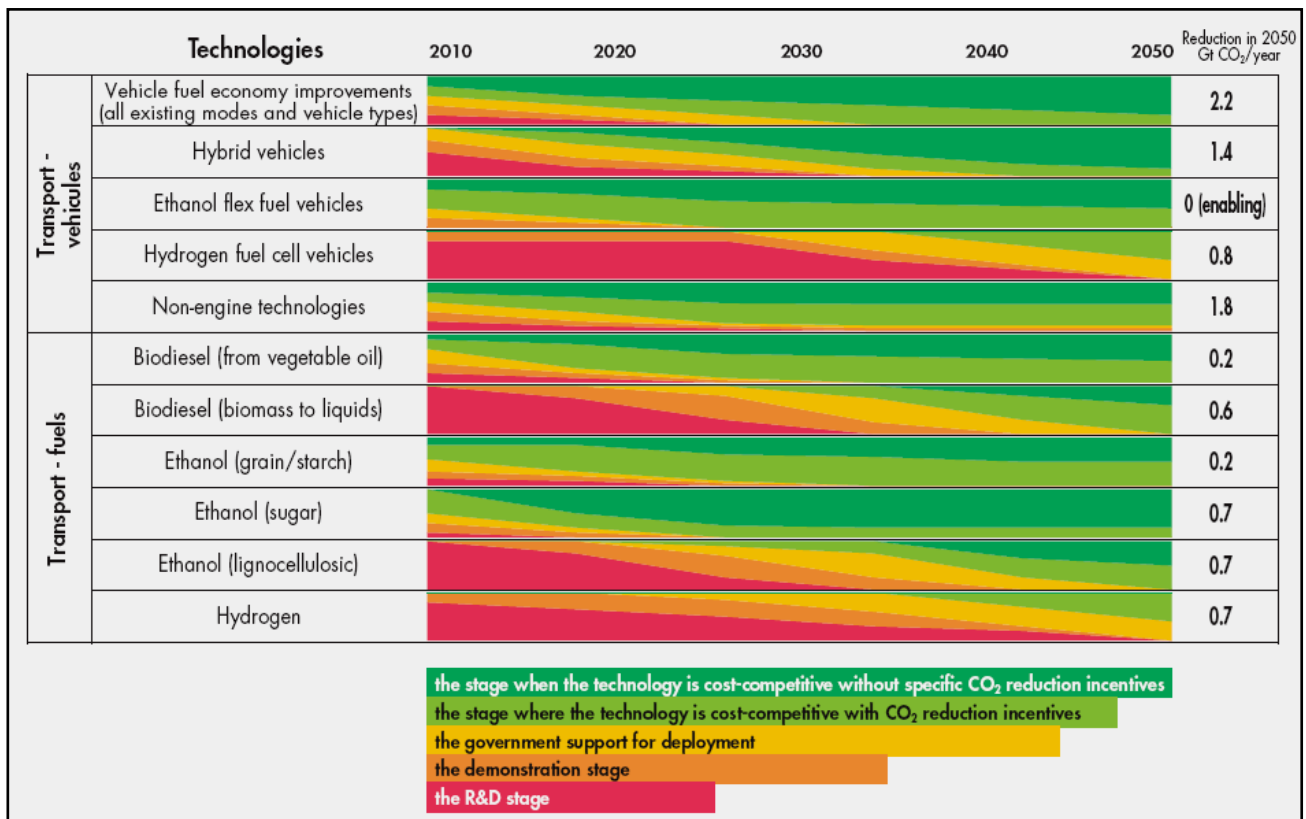
While the WEO APS essentially rests on existing technologies, the ETP ACT supposes the broad dissemination, mostly after 2030, of various technologies that are currently under development. To some extent they are already known but require technical improvements to make them less costly or more acceptable.

“A new energy technology will typically go through several stages to overcome technical and cost barriers before it becomes cost-competitive. Even if a technology is technically proven after the R&D and demonstration stage, costs may still be too high for the market. This is often referred to as the “valley of death” that new technologies face on the way to full commercialisation.” (IEA, 2006b) There might then be a trade-off between prolonging the R&D phase to reduce market entry costs and engaging in early deployment of the technology to benefit from earlier learning-by-doing.

Numerous examples are given in the ETP publication (IEA 2006b). Solar photovoltaic for producing electricity is one of them. It is already commercial in niche markets such as off-grid applications in remote areas. Its long term technical potential is huge, but unless there is a (unpredictable) technological breakthrough it is not expected to become ready for mass deployment before 2030 at a CO₂ reduction incentive of USD 25/t CO₂.

Figure 7 illustrates the pathways towards cost competitiveness for various efficient transport technologies. While some can be disseminated already others will not be affordable for a long time. Although bringing new technologies to cost-effectiveness often requires an early introduction in markets with some financial support scheme, it is only when this stage is reached that the new technologies can really make a dent in the GHG emitting infrastructure. For instance, despite its impressive growth rate in the last ten years, wind power is only now beginning to appear as a significant contributor in the global energy statistics.

Figure 7: Pathways towards cost competitiveness for transport technologies



Source: ETP, figure 3.10, p.137

It is also worth noting that technology development remains partly unpredictable. The assumptions underlying the various ACT Scenarios are based on technology learning as deployment increases. Although this is based on historical experience with various technologies, ultimately there is no guarantee that cost reductions will follow past trends or the trends of similar technologies. Ultimately there is therefore uncertainty in how the technology progress will relate to policy decisions but also to various assumption regarding unpredictable technology or scientific developments. The TECH Plus scenario is more optimistic than the ACT scenarios and is somewhat speculative, as it goes beyond what is considered likely in the ACT scenarios (critically, for hydrogen and fuel cells, it is based on technological breakthroughs). The differences in emissions in these various scenarios are significant, and so would be the differences in abatement costs for achieving a given emission level depending on the various underlying assumptions. For instance, in the ACT No CCS scenario, the marginal CO₂ emission reduction incentive in Europe to achieve the same global CO₂ reduction as in the ACT Map scenario would be USD 43/t CO₂ and USD 40/t CO₂ in China, substantially above the USD 25/t CO₂ in the ACT Map scenario.

3.3 Capital stock turnover slows progress

We live in innovation societies, and it may seem that innovations disseminate rapidly, changing our productive base and infrastructure in years. Moreover, the pace of this change seems ever accelerating. It took over 130 years before one billion landlines were connected. It took only 20 years for the cell phone to get one billion subscribers. And in 2006 alone one billion handsets were sold.

While this holds for product innovation, it does not necessarily hold for process innovation. For industry there may not be new markets and new clients to conquer through a process innovation, but costs to cut in saving work or energy or raw materials or waste and pollution or all. In competitive market cutting costs

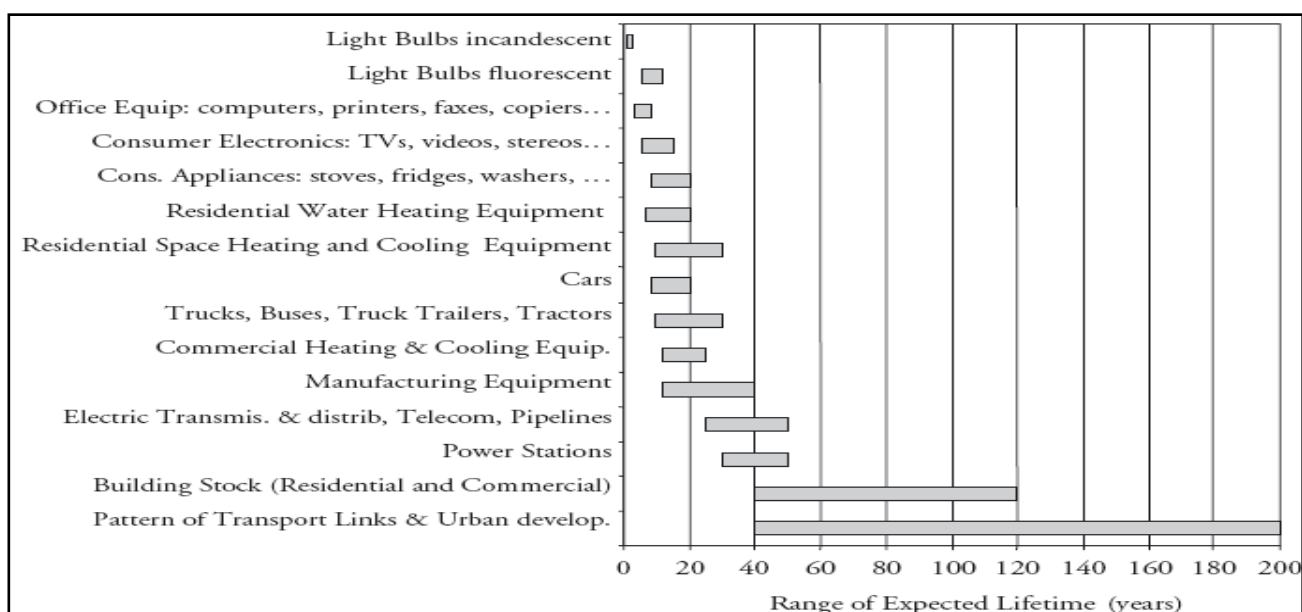
certainly is a constant concern but the equation is not that simple, as high up-front capital costs have to be paid for when introducing process innovation. More energy efficiency projects in industry will be economic if external costs are endogenised, but other non-price barriers also exist.

As illustrated on Figure 8, technical life-times of CO₂ emitting technologies (directly or indirectly) extend from months or years (e.g. light bulbs, some appliances) to decades or even more (power plants, buildings, urban patterns driving transport needs...). As a result, even in modern countries with strong economic growth, the underlying infrastructure may be rather old. For example, “*roughly two-thirds of the electric power plants ever built in the US, and half of those built in the first half of the 20th Century, are still in operation*”. (Lempert et al. 2002)

Capital stock turnover does not come down to nominal lifetimes of equipments. On the one hand, many plants last much longer than their nominal lifetimes, often an accounting convenience, as Lempert et al. (2002) explain: “*For instance, regulated electric utilities were allowed to pay back the capital costs of a plant over some pre-determined lifetime, which regulators generally set at 20 to 40 years. But a plant at the end of the payback period is not necessarily any more ready for retirement than a house with a paid-off mortgage would be.*” On the other hand, infrastructure with very long lives regularly undergo minor to major revamping. Over years, an “old” plant can be entirely or almost entirely new through successive process (and sometimes product) changes and renovations, exactly like the colloquial “grandfather’s axe”, which had three new heads and four new handles but is still the same old axe.

While these changes can be as many opportunities for introducing more efficient and/or cleaner technologies and reduce emissions at relatively low costs, these might remain “*limited by the constraints of its original, decades-old design*” (Lempert et al. 2002). The grandfather’s axe might have more efficient blade and handle but that does not turn it into a chain saw. Similarly, retrofitting buildings can improve their insulation but may not be able to make them using free solar inflows on a larger scale through passive architecture designs as could be the case with new buildings. Things may be even more complicated if the handle and the blade belong to different players, as in the case of fuel distribution infrastructure and car industry (and ownership). Moving from liquid fuels to hydrogen, for example, creates a difficult chicken-and-egg problem, as both the fuel providing system and the fuel using engines must be changed altogether.

Figure 8: Average life-spans for selected energy-related capital stock



Source: Philibert and Pershing, 2002, figure 2, p. 32

The rate of introduction of climate-friendly technologies in the marketplace, without premature capital scrapping, is limited to the rate of capital stock turnover, if emission reductions are to remain affordable.

While energy savings often justify greater up-front investment in new capital stocks, they rarely justify, or only marginally, premature capital stock replacement. Even a high CO₂ price may not significantly change this picture. If CO₂ is priced, climate-friendly technologies may become cost-effective at the time of building new equipment or replacing another, while the cost of emission abatement driven by premature replacement would be much higher.

Even if a plant is inefficient compared to what modern technology can offer, this inefficiency must be very large in order to outweigh the costs of building a new, more efficient plant while also sustaining the loss of production from the one it replaced. Thus *‘advances in process technology have a very high barrier to overcome before they drive changes in capital stock.’* (Lempert et al., 2002). To the cost of a new plant one must add the cost of the required land surface, or the cost of dismantling and cleaning the land of the old plant. In most industrialised countries it is no longer possible to let ancient industrial installation rust and leave contaminated soil behind.

This problem is exacerbated by the uncertainty on future costs and benefits. Using real option analysis, Blyth and Ming (2006) show how uncertainties on future fuel costs or carbon prices leads to defer investment in more efficient or cleaner technologies.

However, several options exist, such as retrofitting, fuel switching, etc. that could be help mitigate emissions at acceptable costs despite slow capital stock turnover. Retrofitting that would occur independently of energy efficiency or pollution concerns could indeed be considered partial capital stock turnover, but retrofitting could also be directed by energy efficiency or environment concerns.

The value of retrofitting is a combination of the improvement over current design and the remaining lifetime of the plant or other infrastructure. There is often a trade-off here, as the oldest plants are usually the least efficient but may not last very long, while retrofitting a younger plant may provide smaller improvements but likely to last much longer. The assessment needs to consider the possible extension of the lifetime of the said infrastructure that retrofitting may allow.

The pace of capital stock turnover is therefore crucial to the rate at which low-carbon technologies can penetrate. This implies that there is a limit to the rate of decline in CO₂ emissions, assuming the technologies are available at low-cost (something that is not guaranteed in some sectors), without the significant increased costs of premature capital replacement. As notes the WEO (IEA 2006a), *“In most cases, capital stock is replaced only gradually, so technological developments that improve energy efficiency will have their greatest impact on market trends towards the end of the projection period”*. Similarly, the ETP (IEA 2006b) notes about policies already enacted that *“Many of these policies will have an effect beyond the 2030 timeframe because of the long lifetime of much of the energy-using capital stock. The lifespan for power plants is forty years or more, while building structures may last sixty years, a century or longer.”*

However, capital stock turnover should not be seen as a purely exogenous constraint. Policies that aim at promoting cleaner and/or more efficient technologies may have a significant impact on the capital stock turnover itself. Pricing CO₂ emissions, for example, modifies the cost structure of the consumption of fossil fuels and could speed the retrofitting or replacement of equipment. Renewable portfolio obligations may speed the displacement of surplus capacities. In some cases, standards could even prohibit extended use of obsolete and particularly inefficient equipment. Various other measures selectively focussed on cleaner technologies or not, such as the accelerated depreciation or expensing of new equipment and a wide array of fiscal incentives may even be primarily designed to accelerate the turnover of capital stock.

4. Policy conclusions

Technology development lead time and slow capital stock turnover are important factors that could limit the rate of reduction in CO₂ emissions. A number of possible policy conclusions can be drawn from the IEA scenario work and other analysis. Four are suggested for discussion in this section.

4.1 Important changes beyond 2030 require important efforts before 2030

R&D but also learning-by-doing processes are needed to develop new technologies. Moreover, long-term departure from current emission trends rest on the cumulative nature of the efforts, and the rhythm of this accumulation depends on the rate of capital stock turnover.

For example, if the introduction of a new energy efficiency standard for buildings in 2006 only makes a change for the 1-2% of new buildings erected each year in a given country, the total number of buildings with such standards applied will be around only a quarter of the total building stock at the end of the 2030 timeframe, and 44% at the end of the 2050 period.

For changes that would rest on technologies not yet ready, the delays due to capital stock turnover and to technology development lead time would essentially cumulate – although to some extent final technology maturation can take place after some early introduction of the technology in the marketplace. One or the other aspect may dominate in different fields. For buildings, most efficient technologies already exist and capital stock turnover may be the most important factor driving the pace of improvement. With respect to the consumption of appliances or cars, although much could be done already with existing technologies, the time for the development of some radical alternatives is likely the most important factor. With respect to electricity production, both factors seem worth considering.

Wigley, Richels and Edmonds (1996) and other analysts advanced several economic reasons to justify deferral of significant and thus more expensive abatement efforts. One is *technical progress*, i.e., greater availability in the future of low-cost substitutes for carbon-intensive technologies. Another is the *cost of capital stock adjustment*, i.e., having more time available for the economic turnover of existing plant and equipment.

While these dynamics must certainly be taken into account if mitigation costs are to remain affordable, it might be argued in the same time that, because capital stock turnover is slow and lead time for new technologies is long, changes should be introduced as soon as possible. If new policies were not introduced before 2030, the subsequent emission pathway could still be curved downward, but the peak would be further away and the reduction in a given year much lower – as somewhat illustrated by the modesty of the changes in the WEO Alternative Policy Scenario relative to the Reference Scenario.

4.2 Long-term price/policy signals are required

Developers in new technologies and investors in new capital stock must be given robust long-term signals to develop the appropriate technologies, learn by doing and bring them to competitiveness (given a carbon price). This necessity is illustrated by the assumptions underlying the various ETP ACT scenarios, and by a significant amount of literature (Philibert 2003).

The price signal should be as certain as possible, as uncertainty may deter investments. This does not imply that the prices must be constant, just that investors need to have a clear long-term signal that avoiding CO₂ emissions has a value. The price of carbon could and probably would fluctuate, but this kind of price risk can be incorporated into business planning processes, just as managing the price risk of other capital or input factors is part of every business. In fact, if the present value of carbon is to remain the same for immediate or

future emission reductions that may arise from current investments, the price of carbon should indeed, grow over time at a pace equal to the discount rate.

Another justification for long-term price signals is the need to limit possible “rebound effects” that may arise from energy efficiency improvements driven by pure technological improvements. And there might be other, somewhat surprising effects, of technology development if carbon is not priced in the future. For example, investing today in new coal plants is somewhat risky, as carbon may be priced in the future. However, the potential of the future availability of CCS to drastically reduce CO₂ emissions from power plants reduces the risks of investing today in new coal plants, as noted by Blyth and Ming (2006).

4.3 Short-term emission targets cannot drive all necessary action

Advantages and possible downsides of short-term fixed quantitative targets directly addressing greenhouse gas emissions have been assessed in the literature (e.g. Philibert 2006), and alternatives considered extensively in previous and current AIXG work. Short-term targets do credibly launch a movement and help every market player figure out the seriousness of the issue; however, given the cumulative importance of the efforts, short term targets matter more in obligating market players to search for sustainable solutions than for their direct short term effects on global emissions.

Additional considerations can be drawn from the analysis in this paper. Short term emissions targets may not suffice to induce the kind of R&D efforts and investments that would command modest short term but significant long term changes in emissions.

More specifically, a country may achieve its short term target while not having developed the policies necessary for the deeper long term changes. Conversely, another country may not achieve its short term target but still have created a greater room to manoeuvre for the long term, either by stimulating more R&D efforts on forthcoming cleaner technologies or by implementing policies with small short term effects but important long term cumulative results, such as tightening energy efficiency standards for new or refurbished buildings, or both.

This remark applies to domestic efforts driven by quantitative emission targets, and would likely apply as well to emission reductions achieved in the context of the various flexibility mechanisms, either plain emissions trading or project-based mechanisms.

Some other kinds of short term targets may help fix the shortcomings of short-term emission targets, as they can be based on a longer term perspective. For instance, in the ACT Map scenario, CCS plays a vital role from 2030 onwards. However, this is based on technology learning reducing the costs of CCS from around USD 50/t CO₂ today to USD 25/t CO₂ by 2030. A vital short-term goal to achieve this would be having 10-15 full-scale commercial coal-fired plants operating within the next 10 years. Another relevant example would be the ever-expanding regulations favouring renewable in many countries, which are expected to bring their costs closer to competitiveness through learning-by-doing processes.

4.4 Developing countries offer significant opportunities – and challenges

The structural differences between the various national economies can lead to significant differences in the rate of growth of the various sectors and the rate of capital stock turnover. In particular, developing countries building a considerable amount of energy-intensive equipment at a rapid rate to satisfy the basic needs of their population present a considerable challenge for policy makers, with a risk of “lock-in” in high-emissions pathways. Conversely, they also offer a great amount of opportunities to introduce more climate-friendly technologies when this is the least costly. In other words, as writes Socolow (2006), *“Much of the world’s construction of long-lived capital stock is in developing countries. Unless energy efficiency and*

carbon efficiency are incorporated into new buildings and power plants now, wherever they are built, these facilities will become a liability when a price is later put on CO₂ emissions”.

Developing countries may also be good candidates for retrofitting options at recently built plant. This can be exemplified by the case of coal plants and CO₂ capture and storage, as explains the ETP (IEA 2006b, p.185): *“Construction of coal-fired stock in the United States peaked around 1970. Given a lifespan of 40 to 60 years, many plants will have to be replaced between 2010 and 2030. Therefore, retrofitting existing plants will probably not be a favoured option but is still possible for larger units with higher steam parameters. In Japan and China, the bulk of coal-fired power plant stock is under 15 years old, so retrofitting existing stock may be a good option. Indian plants are on average 20 years old, which may offer retrofit opportunities.”* In other words, young nations have both forthcoming and existing but young infrastructures; the former offer cheaper emission reduction options than retrofitting, the latter offer cheaper emission reduction options through retrofitting, as the retrofitting investment, lasting much longer, will be economic over a longer time period and result in much higher cumulative emission reductions.

Project-based mechanisms like the Clean Development Mechanism can be considered as first attempts to bridge the gap between the technological resources of the developed countries and the many opportunities to reduce emissions – relative to baseline – in developing countries. The various ETP ACT Scenarios leave no doubt that for global energy-related CO₂ emissions to stop increasing and start decreasing, emission reductions below baseline trends in developing countries will need to be phased in on a massive scale.

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Glossary

ACT Scenario	ACcelerated Technology Scenario
ACT Map Scenario	ACcelerated Technology Map Scenario
APS	Alternative Policy Scenario
CCS	CO ₂ Capture and Storage
ETP	Energy Technology Perspectives
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
R&D	Research and Development
SRES	Special Report on Emission Scenarios
WEO	World Energy Outlook