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Scenarios and Strategies for CO_2 Emissions Reduction

Dolf Gielen[1]
[1] International Energy Agency
9 Rue de la Federation
75739 Paris, France
E-mail: dolf.gielen@iea.org

ABSTRACT

A halving of global greenhouse gas emissions is needed between now and 2050. This will require an energy technology revolution. All options must be used: energy efficiency, CO2-free fuels and CO2 capture and storage. The power sector will be especially affected and the global average carbon intensity of electricity needs to be reduced by one order of magnitude. A mix of renewables, nuclear and fossil fuels with CCS will be needed to achieve this goal. This development will affect gas turbine sales and their development.

INTRODUCTION

Secure, reliable and affordable energy resources are fundamental to economic stability and growth. The erosion of energy security, rising energy costs, the threat of disruptive climate change and the growing energy needs of the developing world - all pose major challenges to energy decision makers. What visions of the future that address these issues are technically feasible and available? Where do we need to focus? And who needs to act and when?

The recent IEA study *Energy Technology Perspectives 2008* (ETP) provides an analysis of the status and future prospects of key energy technologies, and shows how they can contribute to a more sustainable, secure and least-cost energy system (IEA, 2008). It explores how technology can change our energy future, and outlines the barriers to the implementation of change and the measures that would be needed to overcome these barriers.

The goal of the analysis is to provide a technology perspective on the feasibility and costs of deep emission reductions; the book includes various scenarios, amongst them an extremely ambitious one, showing how CO_2 emissions could be reduced to 50% below current levels by 2050 and how oil demand could be lowered by 27% by this time. This study also contains roadmaps for all technologies that play a key role in the emissions halving scenario. It does not deal with the political feasibility of such targets. However, the results make clear that all countries need to act in the next few years if the goal of halving emissions is to remain affordable. In fact the analysis suggests that such action could also greatly enhance the supply security.

The challenge is huge, given that energy CO_2 emissions have been accelerating in recent years. Plus, economic activity is projected to grow by a factor of four between now and 2050, from around USD 50 trillion GDP per year to around USD 200 trillion per year. This growth is essential to lifting millions in developing countries out of poverty, and the same economic growth rate has been applied in all scenarios. However, it means that without further action, baseline energy use could double and emissions could increase by 130% by 2050.

Reducing demand for energy services can therefore only play a limited role. But technological change can help industrialized countries and emerging economies alike. In ETP, the IEA analyses -- amongst other scenarios -- what would be required to achieve the most ambitious scenario of the Intergovernmental Panel of Climate Change (IPCC). In its 4th report, the IPCC says that only by reducing global CO_2 emissions by 50% to 85%, compared to 2000 emissions levels, can we expect to limit temperature increases to 2-2.4°C. G8 leaders agreed at their 2008 Hokkaido Summit to

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emissions halving by 2050. What needs to be done to make this happen from an energy point of view? The answer is sobering but attainable: We need a global energy technology revolution, a complete transformation in the way we produce and use energy, with action required globally in the next few years.

Electricity supply and demand will be significantly affected. The efficiency of electricity supply, transmission and distribution and use needs to be maximised. Electricity supply needs to be virtually decarbonised. The mix of CO_2-free power supply options will vary worldwide, depending on natural resource endowment, consumer preferences and other factors. In the longer term, electrification of the demand side may play an increasing role, for example heat pumps and electric vehicles.

THE BLUE SCENARIOS AND THE ROLE OF ENERGY TECHNOLOGY

The analysis is built around three sets of global energy technology scenarios. These are a Baseline (business-as-usual Scenario), ACT scenarios aiming for emissions that are in 2050 mitigated to today's levels and a range of BLUE Scenarios showing how CO_2 emissions could be reduced to 50% below current levels by 2050.

A 50% reduction of worldwide emissions by 2050 (as in the BLUE scenarios) would be an extremely challenging target. This would require measures with a cost of up to USD 200/t CO_2. With less-optimistic technology assumptions, notably in transportation, costs could be USD 500/t CO_2. The transition cost will be considerable. The average emission reduction costs in this scenario are about a fifth of the marginal cost, and range from USD 38/t CO_2 to USD 117/t CO_2.

In total, five variants have been analysed for the power sector for BLUE scenarios. These are:

- MAP – relatively optimistic for all technologies.
- High nuclear (hi NUC) – 2000 GW instead of 1 250 GW maximum nuclear capacity.
- No carbon capture and storage (no CCS).
- Low renewables (lo REN) – assuming less cost reductions for renewable power generation technologies.
- Low end-use efficiency gains (lo EFF) – assuming a 0.3% lower annual energy efficiency improvement, compared to MAP.

The ETP scenarios require a broad portfolio of technologies to be used. End-use efficiency accounts for 36% of all savings in the BLUE Map scenario, renewables for 21%, and CO_2 capture and storage 19%. The remaining 24% is accounted for by nuclear, fossil fuel switching and efficiency in power generation (Figure 1). Some flexibility exists to vary these shares, which is reflected through the five scenarios for the power sector and four for transport. Improving energy efficiency should be a priority. Many efficiency measures can be implemented with relatively short lead times, and full life costs are often negative.

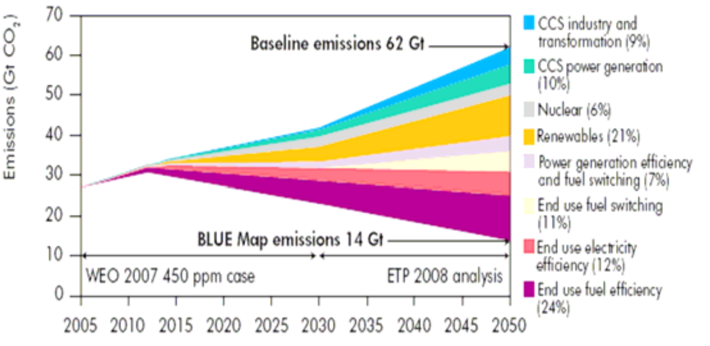

Fig. 1 Contribution of emissions reductions options in the BLUE Map Scenario of ETP 2008, between 2005 and 2050 (IEA, 2008a)

First, we must harvest the huge efficiency potential in all of our economies. Energy efficiency has the greatest potential for CO_2 savings at lowest cost and is in many cases even paying off. And results can be delivered soon. The IEA submitted 25 energy efficiency recommendations to the G8 Summit in Hokkaido, covering seven priority areas: buildings; appliances; lighting; transport; industry; power utilities and cross-sectoral activity (IEA, 2008b). The proposed actions could save around 8.2 gigatonnes (Gt) CO_2/year by 2030. This is equivalent to around one fifth of global reference case CO_2 emissions from the energy sector in 2030.

The G8 has taken up this challenge and launched in July 2008 the IPEEC initiative (International Partnership for Energy Efficiency Cooperation) that will aim for widespread deployment.

Second, we must decarbonise the power sector. Given the growing demand for electricity, this would mean that 35 coal- and 20 gas-fired power plants would have to be fitted with carbon capture and storage (CCS) technology on average per year between now and 2050. The price tag is high -- a single 500 megawatt (MW) coal-fired power plant with CCS costs around USD 1.5 billion today, and costs are escalating. In addition, we would have to build an additional 32 new nuclear plants each year. The latter also implies numerous issues that would need to be overcome, such as the questions of public acceptance and the availability of geologically stable sites for nuclear reactors or waste storage. Wind capacity would have to increase by approximately 17.500 turbines annually.

Although such rates of new technology adoption may seem daunting, the historical rate of nuclear addition and that of current onshore wind additions suggest that they are achievable. Total investments in CO_2-free power generation need to increase six- to sevenfold, from around 50 gigawatt (GW) per year today, to 330 GW per year in the period 2035-2050.

The BLUE scenario also requires widespread adoption of very energy-efficient buildings, with near zero emissions; and, on one set of assumptions, deployment of nearly a billion electric or hydrogen fuel cell vehicles. Sales of conventional vehicles with internal combustion engines would be all but phased out in 2050. Plug-in hybrid electric vehicles and battery electric vehicles have emerged as a promising strategy and are now a key part of some of the more ambitious scenarios.

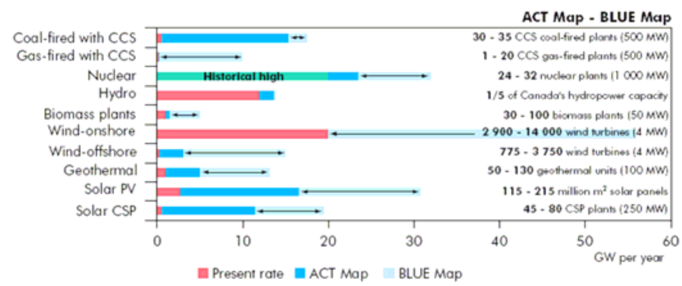

Fig. 2 Annual investment in the electricity sector in the ACT Map and Blue Map scenarios, 2010-2050 (IEA, 2008a)

While energy efficient equipment is available today, more ambitious standards and regulations are needed to ensure its rapid uptake. Significant cost reductions will also be needed in some cases in order to lower the cost of abatement in difficult market segments. The average energy efficiency in 2050 needs to be twice the level of today, a significant acceleration of efficiency improvements compared to the developments since 1990, when they averaged only 1% per year on OECD countries.

The Baseline scenario (which assumes that policies won't change) would require a massive expansion of fossil fuel production, to an extent that calls into question supply availability. For example oil production would have to rise from today's level of around 85 million barrel per day to around 135 million barrels a day in 2050. Even if such an expansion was feasible, it would require a massive production of oil from unconventional resources.

In contrast, oil demand in BLUE Map in 2050 would be reduced 27% compared to 2005 levels. Such a development would certainly ease the supply challenge. However even this level of production will require massive investments in new supply in the coming years and decades as oil fields are depleted. Total fossil fuel demand in the extreme BLUE Map scenario in 2050 is still at the same level as today. So in any case, fossil fuels will continue to be a key pillar of our energy supply in the coming decades.

Most difficult is the transportation sector. But success here brings benefits beyond reduced CO_2 emissions, as lower dependence on oil in this sector would enhance supply security. A combination of "second-generation" biofuels from ligno-cellulosic feedstocks (straw, woody biomass residues, grasses) which should have a far superior CO_2 balance and less competition with food crops than current (1rst generation) biofuels, battery-driven electric vehicles and/or hydrogen fuel cell vehicles will be needed. This, in combination with maximized fuel efficiency across all transportation modes, would achieve the reduced oil demand in 2050 mentioned above. The share of biofuels alone could rise to over 25% of world transport fuel use in 2050, if sustainable approaches were developed and transport fuel demand is dramatically cut via efficiency measures. Change will not happen overnight. In fact oil demand will continue to rise for some time before it starts to fall. We call upon all producers to make adequate investment and expand their production in the coming decades to meet this demand.

To meet the BLUE scenarios, we need to urgently develop and implement new far-reaching policies to a degree unknown in the energy sector and to substantially decarbonise power generation. A significant discrepancy exists between current trends and the BLUE scenario targets. We will need to launch in the coming decade a global revolution in the way we produce and use energy, with a dramatic shift in government policies and unprecedented co-operation amongst all major economies.

PROSPECTS FOR THE POWER SECTOR

Electricity production is responsible for 32% of total global fossil-fuel use and 41% of energy-related CO_2 emissions today. Improving the efficiency of electricity production therefore offers a significant opportunity to reduce the world's dependence on fossil fuels, and helps to combat climate change and improve energy security. A virtually decarbonized power sector is a cornerstone of global emissions halving. Electricity generation becomes largely decarbonised in the BLUE Map scenario, with CO_2 emissions per kWh being reduced by as much as 86%, a reduction by nearly an order of magnitude. The difference in the carbon intensity of electricity production between OECD and non-OECD countries narrows in both the BLUE Map scenario. Renewables, nuclear and fossil fuels with CO2 capture and storage are three CO2-free power supply options. A mix of these three can be supplemented with demand side measures.

Table 1 provides an overview of energy saving and CO_2 reduction potentials. These savings and reductions could be achieved, if all countries were to apply the same efficiency standards as the most efficient plants in operation today. The energy saving potential is 500-700 Mtoe, while the CO_2 reduction potential is 1.75-2.50 Gt, 6.5-9.3% of all energy related CO_2 emissions in 2005. Coal-fired plants account for 80% of the savings potential.

Table. 1 Technical fuel savings and CO_2 reduction potentials from improving the efficiency of electricity production, compared to the reference year 2005 (IEA, 2008a)

	Coal	Oil	Gas	**All fossil fuels**
[Mtoe/yr]				
OECD	134-213	12-24	60-81	205-320
G8	112-177	10-17	93-115	213-311
Plus Five	189-244	7-12	7-10	20-27
World	356-504	36-64	105-134	494-702
[Gt CO_2/yr]				
OECD	0.53-0.85	0.04-0.08	0.14-0.19	0.71-1.12
G8	0.44-0.71	0.03-0.06	0.22-0.27	0.69-1.03
Plus Five	0.73-0.95	0.03-0.04	0.02-0.02	0.77-1.01
World	1.40-1.98	0.11-0.20	0.25-0.31	1.75-2.50

In the Baseline scenario, global electricity production increases by 179% between 2005 and 2050 (Figure 3), from 18 196 to 49 934 TWh. In 2050, coal-based generation is forecast to be 252% higher than in 2005 and accounts for 52% of all power generation. Gas-fired power generation increases from 20% today to 23% in 2050. Nuclear decreases to 8%, hydro decreases to 10%, and wind increases to account for 2.5% of all power generation.

The power-generation sector is significantly influenced by CO_2 incentives. Emissions are reduced considerably in the BLUE scenarios, partly due to reduced demand for electricity as a result of end-use efficiency gains. In the case of emissions stabilisation, significant savings in electricity demand in the buildings and industry sectors reduce the need for growth in generation capacity. Nonetheless, electricity demand more than doubles by 2050 in such a scenario. In the more ambitious BLUE Map scenario where global emissions are halved, demand is 12% higher than in the stabilisation scenario, largely because of an increased demand for electricity for heat pumps and plug-in vehicles.

In the BLUE Map scenario, the share of coal is only 13%. The share of gas declines significantly to 17%, reflecting the fact that CCS – applied to virtually all coal-fired power stations in BLUE Map – is significantly more expensive per tonne of CO_2 saved for gas than for coal, which makes other CO_2-free power supply options in many cases a preferred choice.

The efficiencies of fossil-fuel power plants increase substantially in both the ACT Map and BLUE scenarios, to the extent that coal-fired plants with CCS in these scenarios are on average more efficient than coal-fired plants without CCS in the Baseline scenario. Integrated-gasifiers combined-cycles (IGCC) and ultra-supercritical steam cycles (USCSC) can both play a role in this scenario.

In the BLUE Map scenario, only 157 GW of coal-fired capacity is retrofitted with CCS, while 543 GW of new capacity with CCS is installed. In the BLUE Map scenario 817 GW of new gas-fired capacity is equipped with CCS. This includes industrial large-scale combined heat and power generation units (CHP). In addition, black liquor gasifiers are equipped with CCS in both scenarios.

Nuclear power generation presently plays an important role in the Baseline scenario, with capacity increasing from 368 GW to 570 GW in 2050, and output increasing by 41%. As most of the standing capacity must be replaced in the next 45 years, the Baseline scenario implies on average more than 10 new reactors per year. Without this capacity replacement, more CO_2-emitting capacity would need to be built and emissions would be even higher. Nuclear generation share rises further in the BLUE Map scenarios. Nuclear power is constrained in the model at 1 250 GW, in order to reflect growth limitations based on past experience of maximum annual reactor construction rates (about 30 GW per year).

The share of all electricity generation from renewables increases from 18% in 2005 to 46% in 2050 in the BLUE Map scenario. In the BLUE Map scenario, variable renewable generation (wind, Photovoltaics and marine) produces around 20.6% of electricity worldwide in 2050 (about 3 500 GW). To cope with increasing amounts of variable renewables, electricity grids will need to be improved and electricity storage technologies will need to be deployed on a larger scale. But also more backup capacity will be needed. Hydropower but also gas combined cycles and gas turbines will play a role.

Biomass and wind constitute the bulk of new renewables capacity up to 2020 while , solar starts to make a more significant contribution after 2020 Hydro grows continuously over the whole period, but this growth levels off in 2030 to 2050 as the availability of suitable sites poses constraints. Hydro, wind and solar make an equally important contribution in the BLUE Map scenario in 2050.

Approximately two-thirds of the anticipated solar capacity is based on photovoltaics (PV), with the balance coming from Concentrating Solar Power (CSP). The capacity factor for CSP is higher than for PV and therefore generates about 40% of total solar power generation.

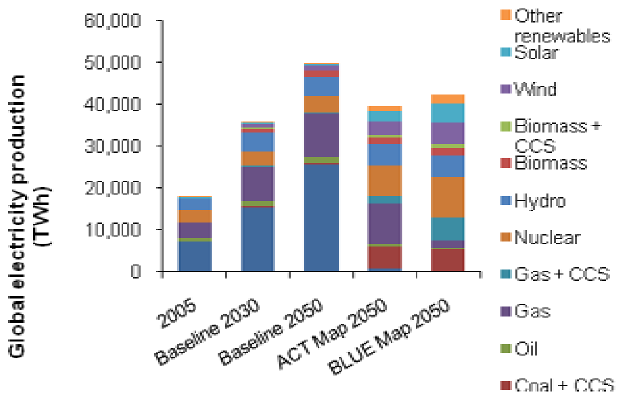

Fig. 3 Global electricity production by fuel and scenario, 2005, 2030 and 2050 – Baseline, ACT Map and BLUE Map scenarios (IEA, 2008a)

About 18 Gt of CO_2 emissions reduction is achieved in the BLUE Map scenario as a result of changes on the supply side. Figure 4 provides a breakdown of the relative importance of the supply-side measures.

In the BLUE Map scenario, power demand is reduced by 24% (7 Gt compared to the Baseline scenario in 2050) due to end-use efficiency measures and reductions in transmission and distribution losses. Electricity demand is raised in this scenario because of switching from fossil fuels to electricity. However electricity use efficiency gains dominate. Compared to the Baseline scenario, demand is 15% lower.

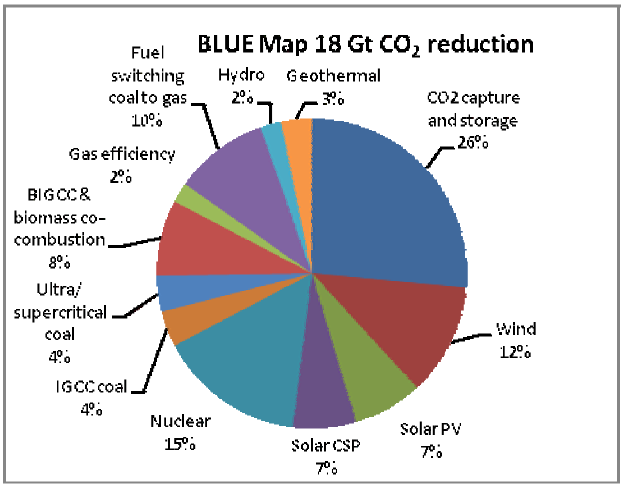

Fig. 4 Reduction in CO_2 emissions from the Baseline scenario in the power sector in the BLUE Map scenarios in 2050, by technology area. Excludes the impact of end-use efficiency and electrification. (IEA, 2008a)

Table 2 provides an overview of power sector results for all five BLUE scenarios. These variants show that total power generation, and the power generation mix, depends on the assumptions that are made in the different scenarios. This suggests that there is some room to choose between different CO_2-free power-generation options. However the CO_2 emission reduction is not the same in all scenarios (Table 2). Especially the CCS option plays a key role. If the same emission target must be met, the investment needs and the marginal costs change significantly. The figures for investment needs and marginal cost in Table 2 refer to the same emissions level as in BLUE Map.

Table. 2 Scenario Results for 2050 (IEA, 2008a)

	BLUE Emissions 2050 [Gt CO_2]	Investment needs 2050 [trln USD/yr]	Marginal cost 2050 [USD/t CO_2]
Map	14		200
NoCCS	20.4	1.28	394
HiNUC	13.4	-0.12	182
LoREN	14.2	0.04	206
LoEFF	15	0.2	230

Among the BLUE variants, the one without CCS has the highest emissions. In this variant the share of coal-fired generation drops by 10%. The share of gas also declines. Total electricity demand is 7% lower and the share of renewables increases. CO_2 emissions increase not only in electricity generation, but also in industry and the fuel-transformation sector. As a consequence, it is not possible to achieve the target of halving CO_2 emissions implicit in the BLUE scenarios. This indicates the importance of CCS for climate policies.

In order to meet the same emissions reduction target the highest additional cost occurs in the BLUE no CCS variant, where the annual cost in 2050 is USD 1.28 trillion higher than in the BLUE Map scenario (Table 2). This is an increase of about 71%. This shows again the critical importance of CCS for deep emission reductions. The impact on marginal costs, as calculated by the *Energy Technology Perspectives* model, is also highest in this case, where they nearly double.

Electricity will also play an increasing role as a CO_2 free energy carrier. The near elimination of CO_2 emissions in the power sector is the cornerstone of achieving deep CO_2 emission reductions worldwide. Advances in new technologies are key to accomplishing this. Fossil fuels used with CCS and nuclear and renewables all play an important role. Each faces challenges. A decarbonised power supply opens the prospect of increasing demand-side electrification as a zero-emission solution for the long term.

Heat pumps can play an increasing role in the buildings sector and for provision of low-temperature industrial heat. Rapid progress in heat pump technology in recent years makes this one of the short-term options for emissions mitigation. In the transportation sector, a massive switch to electric vehicles could create an additional demand for 6 000 TWh that is not fully included in the BLUE Map scenario. Other electrification options exist in industry that can further increase electricity demand. A major advantage of electricity, compared to e.g. hydrogen, is that a transmission and distribution infrastructure exists, which greatly facilitates a transition. However important technological hurdles exist, not the least because of the specific problems of electricity storage.

PROSPECTS FOR GAS TURBINES

The BLUE scenarios have mixed consequences for the gas turbine industry. On one hand, fossil fuel based power generation declines in favor of nuclear and renewable, which reduces the market for gas turbines. At the same time coal fired IGCC capacity will grow faster than in the Baseline scenario as it is a key enabling technology for CCS, which increases the market. Also the introduction of large amounts of variable renewables will require electricity storage and gas backup capacity, either turbines or natural gas combined cycles (NGCC). The optimal mix of electricity storage and backup capacity is not yet clear, but in the BLUE scenarios the capacity ratio is roughly 1:2. New markets will emerge such as gas cooled nuclear reactors and biomass integrated gasifiers combined cycle. The net impact of all these changes is a capacity of power plants with gas turbines in BLUE Map of roughly 5000 GW (table 3). This is 2000 GW less than in Baseline, but still a significant increase from today's levels (1055 GW gas fired power generation capacity in 2004). Including a correction for the steam generation part for NGCC, about 4000 GW of gas turbine capacity would be in operation in 2050. The bulk of the gas fired capacity would have low load factors. This capacity would mainly serve as backup for variable renewables and during periods of peak demand.

However the type of turbines will be different than today. There will be a high premium on efficient turbines. Also a market may evolve for turbines with different gas mixtures, for example oxygen fuelled machines, possibly with CO_2 recycle or hydrogen fuelled turbines (IEA, 2008c).

Table. 3 Total installed capacities of power plants including gas turbines in Baseline and BLUE Map scenarios in 2050

[GW]	Baseline	BLUE Map
Natural gas, turbines and NGCC	6500	3500
Coal IGCC	100	500
Oil residue IGCC	150	100
Biomass IGCC	0	200
Residual gases	50	50
HTGR nuclear reactors	200	500
Black liquor gasifiers	0	50
Total	7000	5000

THE FINANCING NEEDS OF AN ENERGY REVOLUTION

The marginal cost and financing required to achieve these scenarios represent an important outcome of the study. The BLUE Map scenario requires options with a marginal cost up to USD 200/t CO_2.[1] These marginal cost estimates are based on reasonably optimistic assumptions about significant technology cost reductions. Assuming less optimistic cost reductions, notably in the transport sector, would result in the marginal cost for BLUE rising to up to USD 500/t CO_2. A key insight is that the cost uncertainty increases for more ambitious targets, as technologies are needed that are not yet mature and whose future cost are therefore highly uncertain. The average emissions reduction costs in BLUE Map are about a fifth of the marginal cost, and range from USD 38/t CO_2 to USD 117/t CO_2.

The options can be grouped into distinct categories, indicated in Figure 5. This suggests that a generic pricing approach may not be the best way to achieve substantial emissions reductions.

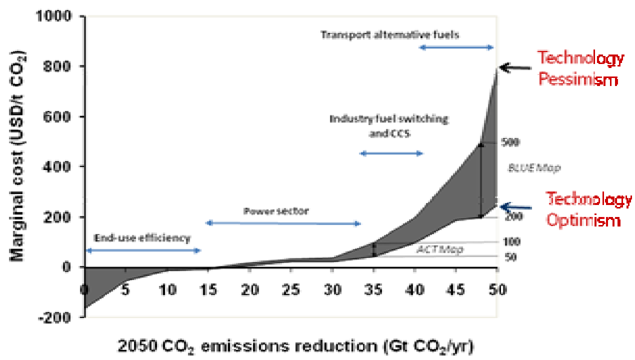

Fig. 5 Marginal abatement cost curve, 2050 (IEA, 2008a)

Increased energy technology research, development and demonstration (RD&D) will be essential. Current technology RD&D investments by IEA governments amount to around USD 10 billion per year, and industry spends around USD 40 billion per year.[2] Efficiency, re-allocation and increased spending can all help to achieve the rate of RD&D change that is needed. Consequently, the actual level of additional funding that is needed is unclear. Literature suggests a range of USD 10 to 100 billion a year. Given the current total level of spending the higher end of this range

[1] USD 200/t CO_2 translates into additional cost of USD 80/bbl of oil.
[2] This is a preliminary estimate. The share of energy spending in total private sector RD&D needs to be analysed in greater detail.

seems more likely.

Apart from RD&D, significant deployment investments are needed in order to achieve the necessary learning effects that reduce the cost of achieving the ACT and BLUE scenarios. Total learning investments – on top of Baseline investments – amount to USD 1.75 trillion between 2010 and 2030, and USD 5.25 trillion between 2030 and 2050 in the BLUE scenario.

The total investment needs in ACT Map for the period 2010-2050 are USD 17 trillion higher than in Baseline, and this rises to USD 45 trillion in BLUE Map. These are the optimistic cost estimates with substantial technology learning and least-cost investments. Investment needs would be higher in the event of less technology learning progress. The investment figures include the investment to achieve massive gains in end-use efficiency, which in turn reduce investment needs in power generation and fuel processing. Clearly the activation of this efficiency potential through standards and regulation will be an important challenge.

The technology mix is another key outcome of the study. The rate of change that is needed is unprecedented. The analogy is not that we need an Apollo project or other grand undertaking, but more likely we need an energy technology revolution. While the necessary technologies are ready or being tested on a pilot scale, their mass application is in many areas still far away, while for many, costs must also come down. The rate of technological change in many areas is in the order of decades. Important issues are the rapid build-up of mass production capacity required, as well as the barrier to rapid change that the life-span of existing capital stock, planning procedures and public acceptance represent.

An important insight is that the future energy system will be determined by decisions taken in the next few coming years and that not acting now with policies to achieve the ambitious long–term goal implied by the BLUE scenario will impose higher costs in the future. Clear long-term targets are needed to convince decision makers in industry to make the capital investments needed to dramatically change our energy system. Technology learning investments are needed to achieve the necessary cost reductions for more sustainable technologies. Energy RD&D levels must be raised and restructured in order to accelerate the development of new energy technologies with superior characteristics.

NEXT STEPS

The IEA has identified roadmaps for 19 groups of technologies that cover over 80% of the total emissions reduction (Table 4). These roadmaps describe the role of technologies in the BLUE Map scenarios, and give RD&D and implementation targets and policy needs for the period between now and 2050 that must be met in order to be consistent with the desired 2050 outcome – so-called transition paths. These roadmaps need further development in the coming months and years, and building an international implementation framework supported by the public and private sector will be essential. Closer international cooperation will be needed. Indicators must be elaborated and used to track progress on the roadmaps. These roadmaps should not be straightjackets but signposts that guide the developments and accelerate the change towards a more sustainable energy future. All roadmaps marked in bold have relevance for the future development of gas turbines.

Table. 4 ETP Roadmaps

Supply Side	Demand Side
• **CCS fossil-fuel power generation** • **Nuclear power plants** • Onshore and offshore wind • **Biomass IGCC & co-combustion** • Photovoltaic systems • Concentrating solar power • **Coal: integrated-gasification combined cycle** • Coal: ultra-supercritical • 2nd generation biofuels • Electricity networks	• Energy efficiency in buildings and appliances • Heat pumps • Solar space and water heating • Energy efficiency in transport • Electric and plug-in vehicles • H_2 fuel cell vehicles • CCS industry, H_2 and fuel transformation • Industrial motor systems • Cement

A combination of much more aggressive RD&D, deployment programmes, investment frameworks, standards and regulations is required to bring these technologies to the mainstream. In terms of the energy mix, no option can be set aside. We need maximum output from all clean energy options.

The ETP analysis shows that technological change must play a key role if deep emission cuts are aimed for. Technology transfer from developed countries to developing countries will be a prerequisite for the widespread adoption of these new technologies.

An energy technology revolution will result in winners and losers in terms of industrial activity. Certainly the level of sophistication will increase. Oil, gas and coal will lose in favor of other forms of energy. Of the 19 key technologies that have been identified in Table 4, only part of those depend on proprietary technology, and often only specific components in the overall technology design. However systems integration of various new components into a well functioning technology needs attention. Also the economics of scale require mass production, which poses technology challenges of its own.

We need to act now, and commit to change as society. Energy efficiency, nuclear energy, CO_2 capture and storage, biofuels, wind turbines and hydropower projects are all solutions that face some level of opposition, but we need them all if we want to succeed in emissions halving. Climate change is such a pressing issue that we can ill afford to delay action in hope of better solutions in the far future. How to balance long-term benefits and short-term burdens is a challenge that needs attention. The uptake and legal processes must be further streamlined. It is possible to combine economic growth and sustainable development. Superior technology is a key component of the way out of maze we are in today. Gas turbines are part of the solution.

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