

Prospects for CO₂ capture and storage¹

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Abstract

This paper discusses new insights regarding the role of CO₂ capture and storage, based on the IEA Energy Technology Perspectives study. Special attention is focused on the impact of CCS on the use of natural gas. The paper concludes that there are opportunities for CCS use for gas processes in the manufacturing industry and fuel transformation sectors, but CCS for gas fired power plants seems a relatively costly emission mitigation option that may only play a role in case of exceptionally low gas prices or in case CO₂ is needed for enhanced oil recovery. On a global level, CCS has limited impact on gas use. Important opportunities exist on the medium and long term for CO₂ capture from coal fired power plants. Total capture and storage could exceed 6 Gt by 2050, as part of a wider portfolio of measures to reduce CO₂ emissions.

Finally the IEA activities on CO₂ capture and storage in the framework of the G8 Plan of Action for Climate Change, Clean Energy and Sustainable Development are introduced.

Introduction

CO₂ capture and storage (CCS) is widely considered a key option for CO₂ emissions reduction in the 2050 timeframe. While CCS will be critical for the role of coal in a CO₂-constrained world, its impact on the future of natural gas is less evident. Both the uptake of natural gas-related CCS technologies and the influence of CCS on gas and coal use are the topic of this paper.

CCS can be deployed to mitigate CO₂ emissions from gas-fired power plants, natural gas processing, and gas-based industrial processes. It is not clear if all three options represent significant abatement potential. In the paper we quantify these potentials on a global scale.

CCS increases attractiveness of gas vs renewables and nuclear, but it also increases attractiveness of coal vs gas. The net effect of these two phenomena on natural gas use will differ by region and by sector, and its impact on a global level is not obvious. In the paper we elaborate more on the interactions between CCS and market for particular fuels and technologies.

The paper presents results obtained using the Energy Technology Perspectives model developed at the International Energy Agency. First we present the model, give basic scenario assumptions and show a role of CCS amongst other abatement options. We focus then on CCS in gas-based processes. Finally, we present results concerning the future coal and gas markets.

All the considerations in the paper are based on an assumption that the CO₂ emissions are given a price of 25 USD/tonne, unless we state otherwise.

Global CO₂ emissions in the Energy Technology Perspectives Model

The Energy Technology Perspectives Model is a technology rich partial equilibrium model of the world energy system. The world is split into 15 regions that can trade energy and material

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commodities. The model uses the MARKAL model algorithm, developed by the Energy Technology Systems Analysis programme, one of the 40 implementing agreements of the International Energy Agency (ETSAP, 2003). The model calculates the system configuration that can satisfy the useful energy demand at minimum cost for the period 2000-2050. It accounts for resource availability, changing energy prices and technology constraints. The core part of the model is a database with about 1500 energy technologies. These technologies cover all supply and demand side processes, from oil refineries to light bulbs.

In a previous study this model was used to assess the prospects of CO₂ capture and storage (IEA, 2004). The model was used for a new scenario study. This study was aimed at finding the best pathways to enhance supply security and reduce CO₂ emissions. The Energy Technology Perspectives study shows how CO₂ emissions can be stabilized at current levels by 2050, and which technology options must be developed in order to meet this target (IEA, 2006). This study included an update of the CCS technology data, e.g. retrofit options and capture-ready power plants. Moreover the energy prices were adjusted upward, in line with the latest IEA projections (IEA, 2005). The gas price in importing countries increases to 6.5 USD/GJ in 2050.

The Baseline Scenario was calibrated with energy demand and fuel price projections of the World Energy Outlook 2005. A new family of scenarios was developed that include new technology policies (IEA, 2006). In this paper we focus two policy scenarios, one with and one without CCS. These two scenarios are based on the following assumptions: new RD&D policies aiming for the widespread use of emerging energy technologies, policies that mitigate the barriers to the uptake of demand side efficiency options and a CO₂ reduction incentive of 25 USD/t worldwide, introduced gradually over the 2015-2040 period. More expensive measures are not applied. The difference between both scenarios with and without CCS provides insights regarding the contribution of CCS technologies to the energy policy targets.

Fig. 1 Global CO₂ emissions

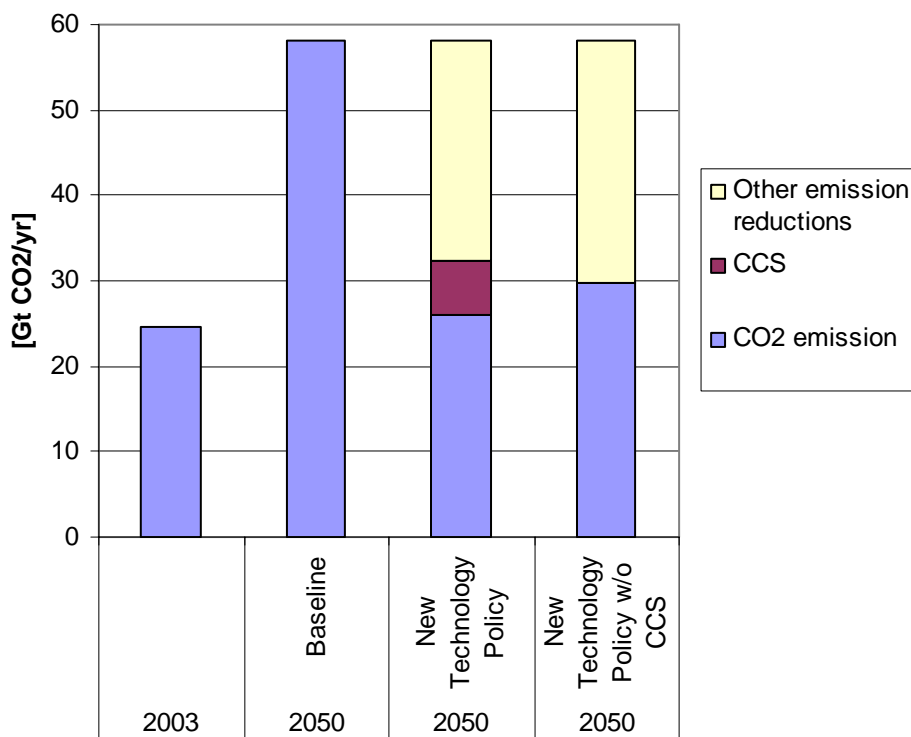


Fig. 1 presents global CO₂ emissions in 2003 and in 2050 under the Baseline Scenario, the New Technology Policy Scenario and the New Technology Policy Scenario without CCS. In a Baseline scenario emissions grow from today's 24 Gt of CO₂ per year to 58 Gt in 2050. In contrast, abatement measures may bring 2050 emissions closer to the current levels. The New Technology Policy Scenario has CO₂ emissions only 6% higher than in 2003. The New Technology Policy Scenario without CCS has emissions that are halved compared to the Baseline scenario. However emissions are about 20% higher than in the scenario with CCS.

The key message from this graph is that CCS could play an important role as a part of a broader portfolio of emission reduction options. Enhanced energy efficiency represents the bulk of the emission reduction. CCS is the second most important option with 6 Gt of CO₂ potentially captured in 2050. None of these options, however, is a silver bullet. Emissions can be reduced significantly if only options up to a cost level of USD 25 /t CO₂ are applied.

CO₂ capture from gas-based processes and competition of gas and coal in a CO₂ constrained world

The most of the existing and announced CCS projects are related to natural gas. This includes the Sleipner project (aquifer storage of CO₂ from natural gas processing), the Peterhead project in the UK (hydrogen production from natural gas with CO₂ EOR, with hydrogen use for power generation), a gas-fired power plants at Statoil's Tjeldbergodden plant in Norway (CO₂ EOR), the In Salah project in Algeria (natural gas processing with storage in the aquifer zone of the gas field), the Snøhvit project in Norway and the Gorgon project in Australia (both natural gas processing projects with storage in saline aquifers).

Table 1: Cost and Parameters of Fossil Fuelled Power Plants with CO₂ Capture and Storage.

Fuel,Technology	Starting year	INV (USD/kW)	Eff (%)	Eff. loss (%)	Add. fuel (%)	Capture eff. (%)	Capture costs (USD/t CO ₂)	El. costs (US\$/kWh)	El. Costs reference plant (US\$/kWh)	Add. El. costs (US\$/kWh)
Likely technologies										
Coal, steam cycle, CA	2010	1,850	31	-12	39	85	33	6.79	3.75	3.04
Coal, steam cycle, membranes + CA	2020	1,720	36	-8	22	85	29	6.10	3.75	2.35
Coal, USC steam cycle, membranes +CA	2030	1,675	42	-8	19	95	25	5.70	3.75	1.95
Coal, IGCC, Selexol	2010	2,100	38	-8	21	85	39	6.73	3.75	2.98
Coal, IGCC, Selexol	2020	1,635	40	-6	15	85	27	5.71	3.75	1.96
Gas, CC, CA	2010	800	47	-9	19	85	54	5.73	3.75	1.98
Gas, CC, Oxyfueling	2020	800	51	-8	16	85	49	5.41	3.75	1.66
Speculative technologies										
Coal, CFB, chemical looping	2020	1,400	39	-5	13	85	20	5.26	3.75	1.51
Gas, CC, chemical looping	2025	900	56	-4	7	85	54	5.39	3.75	1.64
Coal, IGCC & SOFC	2035	2,100	56	-4	7	100	37	6.00	3.75	2.25

Note: Using 10% discount rate. The gas price is USD5/GJ and the coal price is USD2/GJ. Transport and storage cost (excl. pressurisation) are included at 1USD 15/t CO₂ (a high estimate). Load factor 85%.

Source: (IEA, 2004)

All these projects, and especially their storage part, are important for future development of CCS on a global scale. However, the bulk of CO₂ mitigation due to CCS use will come neither from capture

in the gas processing projects nor from gas-fuelled power plants. Gas processing is a source of limited amounts of CO₂ that could be captured (probably not more than 50 Mt of CO₂/year (IEA GHG, 2002). The CCS in gas-fired power plants will probably have limited, local importance as a CO₂ abatement measure because of reasons outlined below.

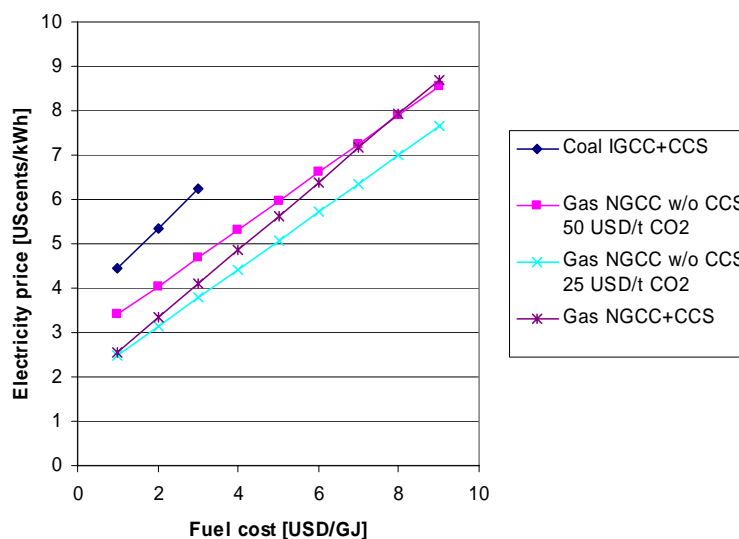
Table 1 presents costs and other parameters of future fossil fuelled power plants with CCS. Gas-fired plants with CCS produce cheaper electricity than coal-fired plants with CCS. Differences are not big, however. Technology progress for gas-fired plants has a limited potential to bring costs down. Capture costs per tonne of CO₂ for gas are much higher than for coal. They range from 49 to 54 USD/tonne of CO₂ (captured) while for coal from 20 to 39 USD/tonne.

The latest natural gas fired combined cycle (NGCC) plants achieve 60% efficiency on a lower heating value basis. This is the highest efficiency of any fossil fuelled power plant. Moreover gas is a fuel with a low CO₂ emission coefficient. Therefore the emissions per kWh are only 335 grammes. In contrast, the latest coal fired power plants emit 750 grammes of CO₂ per kWh. This is more than twice as much. However the CO₂ concentration in the offgases of NGCCs is only 3-4%. Therefore chemical absorption is the only feasible capture technology and this inevitably brings costs up. Alternatively other power plant designs may be considered such as oxyfuelling, chemical looping, or pre-combustion shift reaction and capture. At this moment chemical absorption would be the technology of choice. Future designs may allow a reduction of capture investment cost and efficiency loss.

Clearly this is not a cheap option to reduce CO₂ emissions, more expensive than marginal CO₂ abatement costs necessary to stabilise emissions in the New Technology Policy scenario, for example. Yet the electricity price effect is limited and gas still looks like a viable option, so it could very well become the production option of choice. However, this is not due to the economics of CO₂ capture for gas fired power plants as a mitigation option but due to the attractive economics of NGCC to begin with.

The primary competitor of gas that benefits from CCS is coal. Fig. 2 shows the cost of electricity production. Four investment decisions are compared: coal with CCS, gas with CCS, and gas without CCS for two incentive levels (USD 25 and USD50 per tonne of CO₂). In the latter two cases the utility decides to buy permits and does not reduce emissions. This case has not been analysed for coal because CCS makes sense for this fuel at these CO₂ price levels.

Figure 2: Cost of coal and gas fired electricity production



The least-cost supply option depends on the gas price and the CO₂ reduction incentive. In the US, a coal price would be 1.5-2 USD/GJ and a gas price 5-7 USD/GJ. In such a situation coal + CCS is cheaper than gas with or without CCS at all incentive levels from USD 25/t CO₂ upward. However if the coal price is USD 3/GJ and the gas price is USD 4/GJ, gas fired power generation is cheaper in all cases with incentive levels, either with or without CO₂ capture. In other words small differences in fuel prices can affect the decision-making. While coal prices are relatively stable, gas prices are highly uncertain. Therefore the projection of gas prices is the real uncertainty for the investor.

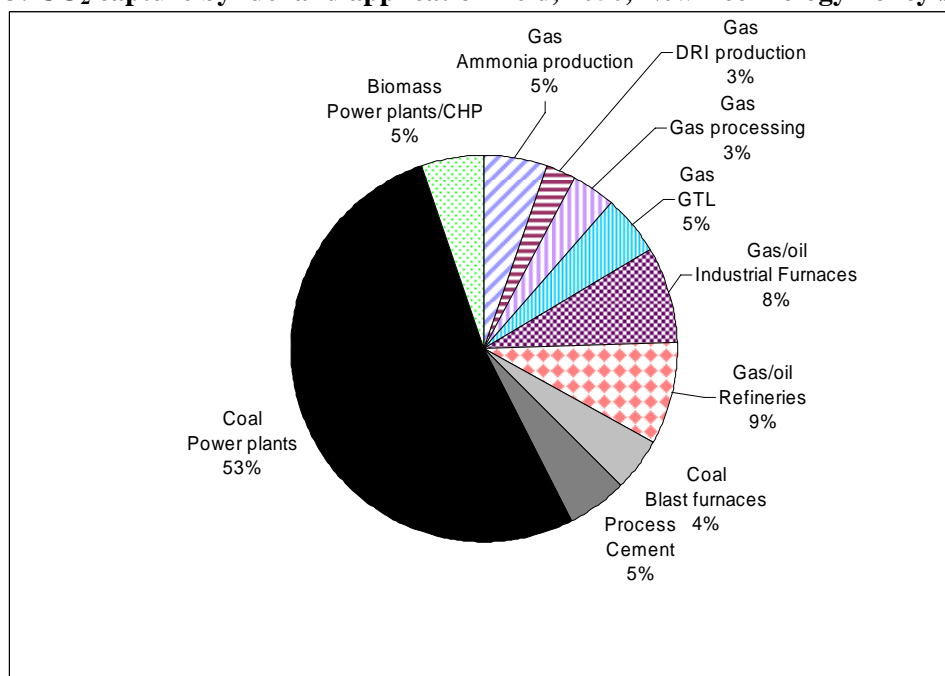
Fig. 2 suggests that the impact of CCS on the gas economics is of secondary importance, especially for high gas prices

While CCS seems a costly option for gas fired power plants, there may be certain cases where it makes economic sense. If the gas price is very low, the cost of CO₂ capture will be low as well. Typically this is the case in regions with ample gas reserves. Oil and gas reserves often occur together. If CO₂ can be used to enhance oil recovery and no other potential CO₂ sources exist, it may make economic sense to capture CO₂ from gas fired power plants. Typically such a situation may occur in *e.g.* Norway, the Middle East or Russia.

Modelling results of CCS deployment, 2050

Fig. 3 provides a breakdown of CO₂ capture by fuel and by process. One third of all CO₂ capture is from natural gas fuelled processes. These are all in the manufacturing industry or the fuel transformation sector. It includes ammonia and Direct Reduced Iron (DRI) production, gas to liquids (GTL) plants, and gas fired furnaces. Also refinery hydrogen production from natural gas is included.

Figure 3: CO₂ capture by fuel and application field, 2050, New Technology Policy Scenario.



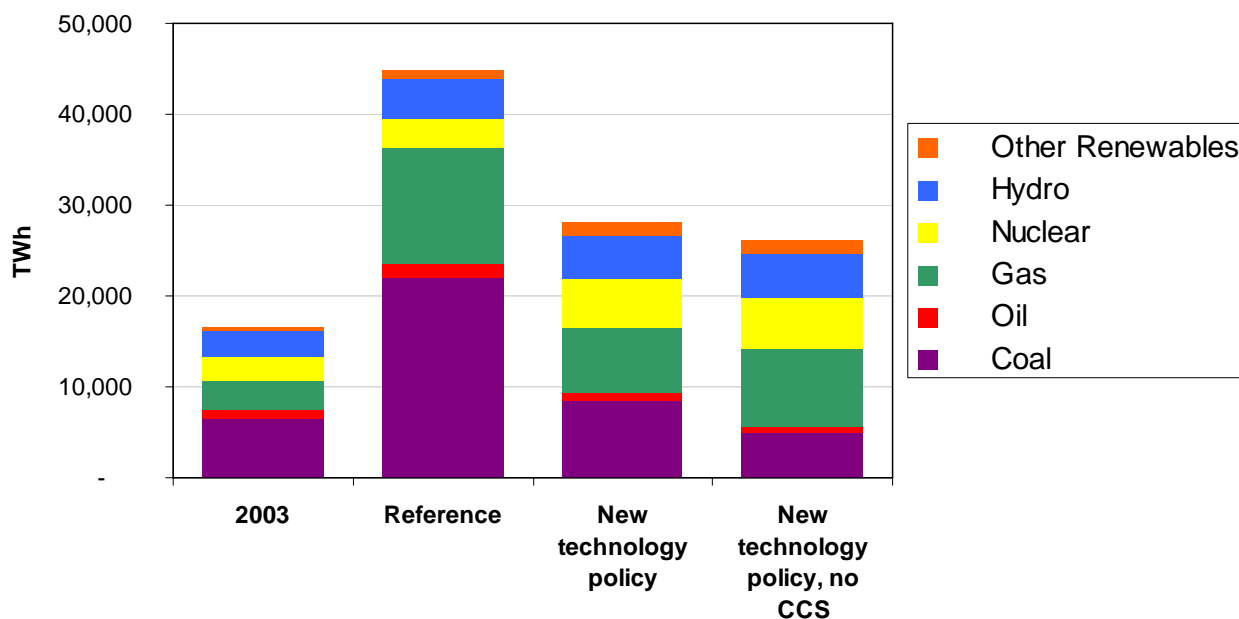
Key point: 33% of all CCS is from gas fuelled processes.

Fig. 4 shows a breakdown of electricity output for the different scenarios. The highest gas demand occurs in the Baseline scenario without CO₂ policy. In all scenarios with CO₂ policy the electricity demand is considerably lower because of demand side electricity savings. Total coal and gas use is lower in the scenario without CCS. This suggests that gas can capture part of the coal market, but

absence of CCS implies less fossil fuel use. Gas use in the power sector is 20% higher if CCS is not available, but coal use declines by more than 40%. The fact that gas does not fill the whole coal niche can be explained by the segmented gas market structure and the high price of natural gas by 2050. In most regions either gas is the cheapest option – without CCS – or gas is too expensive and coal with CCS competes with other options.

A significant share of the gas is in fact used by middle load and peaking plants for which CCS is not an option. These plants will be needed whether CCS is used or not.

Figure 4: Electricity output by fuel, 2003-2050.



CO₂ Capture and Storage in the G-8 Plan of Action

The leaders of the G-8 countries have asked the IEA to fulfill 14 tasks in the framework of their dialogue on Climate Change, Clean Energy and Sustainable Development. One of these tasks focuses directly on CO₂ capture. A workshop on early CCS opportunities is planned in San Francisco, 22-23 August 2006. The focus will be on CO₂ enhanced oil recovery and CO₂ separation from natural gas. This is a gathering of professionals from industry and research institutions, aiming for information exchange and the preparation of dissemination and popularization. It is organized jointly by the IEA working party on fossil fuels, the oil and gas advisory group, Chevron, the US Energy Association, the IEA GHG R&D Programme and the IEA EOR R&D Implementing Agreement. Further conferences and publications on the same topic are planned for 2007.

Capture-ready plants are also part of this task. An engineering and costing study on capture ready plants is supervised by the GHG R&D programme. The IEA Secretariat will publish a report on policy instruments and incentives for capture ready plants. All the CCS activities are closely coordinated with the Carbon Sequestration Leadership Forum (CSLF). Involvement of developing countries and oil and gas producing countries is a key part of this task.

Conclusions

An incentive of 25 USD/t CO₂, in combination with other new energy policies, can bring global CO₂ emissions back to current levels by 2050. In this scenario CCS use would grow to 6 Gt in 2050. More than half of this capture is from coal fired power plants. The CO₂ incentive is not sufficient to warrant capture from gas fired power plants. It would allow introduction of CCS for gas processes

in the manufacturing industry and in the fuel transformation sector. The capture from gas-fired processes would account for about one third of all CO₂ capture.

CCS can play a role in gas-fired power plants in situations with very low gas prices or in case it represents the only local source of CO₂ for enhanced oil recovery. Such a situation may occur e.g. in Norway, the Middle East or parts of Russia.

The impact of CCS on gas use is probably neutral or slightly negative in most markets. If CCS is not available, the use of coal would be significantly lower. However it is not necessarily natural gas that benefits from this market opportunity. Nuclear, renewables and energy efficiency can fill the gap as well, often at lower cost. Only in markets where all these options are not available, natural gas would benefit from not having CCS.

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