Carbon Capture and Storage

Actions to achieve high performance in a low-carbon economy

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Contents

Executive summary

There is an urgent need to close the sizable gap between intentions and actions to reduce greenhouse gas emissions. Power generators and other major users of fossil fuels feel under pressure to change. However, a profound disconnect remains between the scale of carbon reductions required and those achieved.

The global economy relies heavily on fossil fuels, notably coal-fired power, which makes up 41 percent of today's global electricity supply. This reliance, combined with growing demands for electricity, points to carbon capture and storage (CCS) as the only current technology solution that can remove up to 90 percent of carbon dioxide (CO_2) from emissions arising from burning coal, natural gas or oil. We are all aware that burning carbon-laden fossil fuels to meet the planet's power needs is not viable in the long term. Given the potentially long and complex route to replacing fossil fuels, we believe CCS will be instrumental in the transition from today's carbon-intensive power generation to primarily zero-emissions generation, such as nuclear, renewables and other technologies yet to be discovered or industrialized.

Unfortunately, implementing CCS at the scale and magnitude necessary to address climate concerns will not be easy. Governments worldwide have set aside up to $12.5 billion for CCS demonstration plants, which includes at least $8 billion in funding from the European Union (EU),[1, 2] new funding of $2 billion in CCS projects under the Australian CCS Flagships program[3] and $2.4 billion earmarked for CCS in the Obama administration's stimulus package.[4] To put this in context, the renewables sector saw $155 billion of public and private sector investment last year.[5] CCS demonstration projects around the world are trialing techniques to identify the most efficient ways to capture, safely transport and store carbon dioxide below the earth's surface for long timescales. The current funding is a tiny fraction of what will be needed to prove all stages of the CCS value chain and make this technology a viable part of the climate change solution.

The feasibility of CCS at the scale required to make a material impact on CO_2 emissions is subject to a number of uncertainties. First, the cost is currently prohibitive and the extent to which this can be addressed in the longer term by sufficiently high carbon prices remains unclear. Questions also remain about the long-term cost and viability of storage, where more investment in seismological surveys will be key to identify feasible sites. Finally, there are considerations about the legal liability for long-term storage and the legal/regulatory implications of inter-jurisdictional transport. Moreover, reaching scale poses a challenge: Today, awareness is low. There is only a handful of live CCS projects that are injecting CO_2.[6] This number will need to expand several thousandfold to make a material impact, and time is short.

The driving force to answer such questions is strong. Assuming that these uncertainties can be overcome, Accenture foresees a market evolving over three distinct horizons. Horizon 1 focuses on technological demonstration in North America, Europe and Australia; moving to regional commercialization to support viable business models in Horizon 2; and finally, global commercialization, encompassing China and India, in Horizon 3. And if the ultimate aim is to address climate change, we must significantly increase the pace and magnitude of investment now, as well as clear the regulatory complexities with unprecedented speed to ensure a rapid market evolution to Horizon 3, which addresses the majority of the world's remaining CO_2 emissions from coal.

Accenture believes that alongside the renewables and nuclear sectors, substantially more investment, analysis and research and development are needed to work through CCS's complex uncertainties. Governments and industry must dramatically increase their investment and policy commitment to support the demonstration of this technology and to achieve the necessary economies of scale.

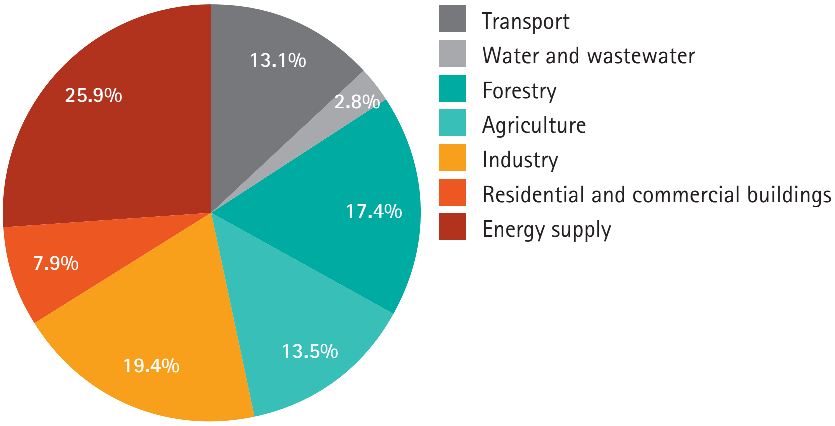
As this plays out, we see potential for new CCS business models to emerge—for equipment manufacturers, financiers, asset owners and third-party service providers—across the value chain from capture to storage. Accenture believes those companies and countries that adapt and progress this technology will enhance their ability to secure a broad-based, sustainable industry that will support them in their journey to high performance in the low-carbon economy.

Introduction

Carbon capture and storage: an essential part of the carbon mitigation portfolio

Today, we remain way off target for a majority of our greenhouse gas reduction goals. For example in Europe, existing measures are projected to move the region less than halfway toward the Kyoto Commitment of -8 percent of 1990 levels of greenhouse gases by 2010.[7] In parallel, global temperatures are rising faster than expected. The Intergovernmental Panel on Climate Change's (IPCC) latest meeting in Copenhagen spoke about the potential for a rise of 7 degrees Celsius by the end of the 21st century, admitting they may have underestimated the scale of the problem, and that emissions since 2000 have risen much faster than expected.[8] Clearly, more needs to be done to translate targets to practical changes in the industry that curb our carbon output.

Figure 1. Global anthropogenic greenhouse gas (GHG) emissions by sector.



Source: IPCC, Fourth Assessment Report: Climate Change 2007 Synthesis Report Summary For Policy Makers (2007), 5. Based on most recent readings (2004).

Electricity generation is the single largest source of anthropogenic carbon dioxide emissions from large-point sources[9] (see Figure 1) and is forecast to be the fastest-growing source to 2050. This is to a large extent owing to the fact that 41 percent of the world's energy production is coal-fired,[10] and the global abundance and relatively cheap nature of coal ensures this trend is set to continue, with China and India rapidly building new coal-fired power stations. Although projections vary, power generation capacity is forecast to approximately double to 33,000 tWh by 2030, with fossil fuels, and in particular coal, the majority fuel type[11] (see Figure 2).

Any significant reduction in carbon emissions will require a fundamental shift in the way power is produced. The 2008 International Energy Agency (IEA) World Energy Outlook's most ambitious energy decarbonization policy scenario foresees dramatic change in the power sector—with CCS, renewables and nuclear each playing a crucial role. Renewables and nuclear are already uppermost in the climate change debate, attracting hundreds of billions of dollars in private and public sector investment last year.[12] The hope is that these alternatives will contribute significantly to the future energy supply—in more positive scenarios, more than 50 percent[13] (see Figure 2). However, challenges accompany each of these technologies (e.g., public safety concerns, land requirements and intermittency of supply) and they will need time to reach scale. The reality is that the large, existing asset base of coal and gas stations, and the focus on new-build fossil fuel plants in countries like India and China, demand a solution to decarbonize fossil fuel generation if we are to make real progress toward our future targets.[14]

If we assume continued reliance on fossil fuels, the only currently feasible technology solution is CCS, which has the ability to remove up to 90 percent of CO_2 from coal- and gas-fired energy production.[15] CCS has significant potential to form a bridging technology that takes us from carbon-intensive generation today to a low carbon future. As well as having the potential to lower emissions, CCS can provide new demand for countries' coal reserves and can help those countries achieve greater energy security.

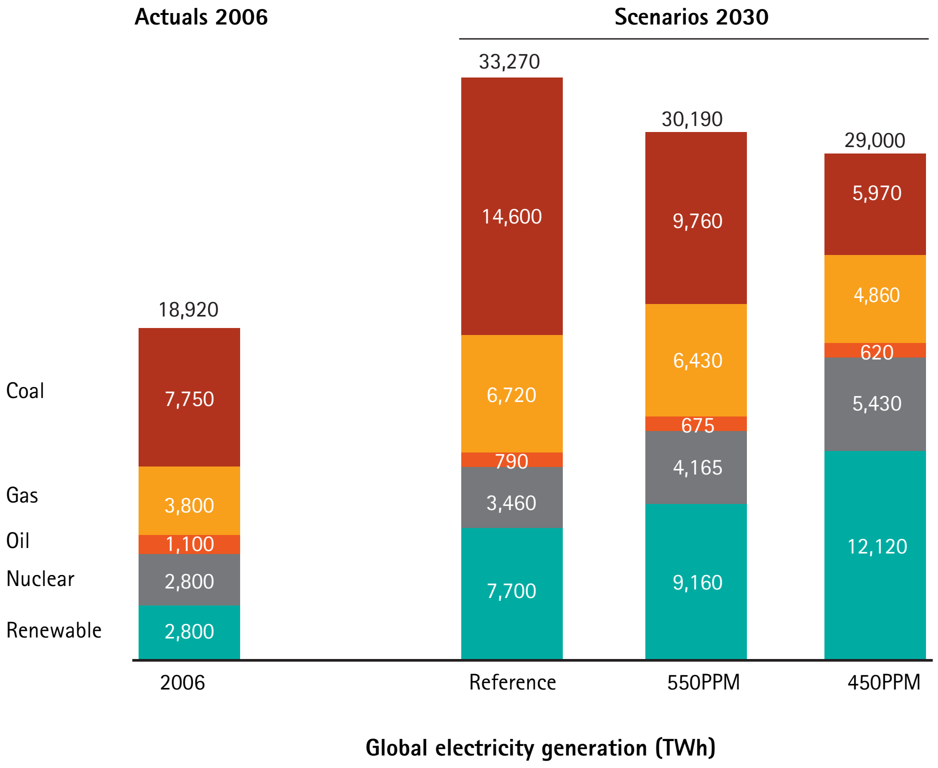
It is also worth noting that the application of CCS is not limited to power generation. It can also be used in CO_2-emitting industrial processes, such as iron, cement and steel production and fuels processing, including refining. These processes account for roughly 24 percent of emissions from large-point sources.[16] The CCS technology to support industrial use is less mature, but in an increasingly carbon-constrained world, these industrial players will grow in importance. As electricity generation is decarbonized, regulators' attention will turn, in the coming decades, from power generation to other carbon-emitting industrial processes.

Industry and governments are reaching consensus about CCS's viability and its profile has risen since 2000. It now regularly features high up the climate change agenda. A recent statement by the UK Secretary of State for Energy and Climate Change reflects this awareness: "There is an urgent international imperative for us to make coal clean. With a solution to the problem of coal, we greatly increase our chances of stopping dangerous climate change. Without it, we will not succeed."[17]

The IEA World Energy Outlook 2008 ACT and Blue Scenarios expect significant contributions from CCS-fitted coal and gas-fired power generation plants in 2050.[18] Governments around the world are responding to this and have set up a significant cash pot for CCS demonstration plants. This includes at least $8 billion in funding from the EU,[19, 20] new funding of $2 billion in CCS projects under the Australian CCS Flagships program[21] and $2.4 billion earmarked for CCS in President Barack Obama's stimulus package.[22]

This is a starting point, but is woefully insufficient if CCS is expected to become a mainstream technology within the next two decades. The IEA estimates that for CCS to deliver any meaningful climate mitigation effects by 2050, it will require 6,000 projects, each injecting a million tons of CO_2 per year into the ground. Today there are only three such storage projects worldwide.[23] Dedicated investment and the ability to design regulatory and policy frameworks that promote carbon-free electricity generation will be key. In this paper we aim to outline some of the key uncertainties and challenges to progressing CCS technology and examine pragmatic means to address them. We also present a framework for how we expect the CCS marketplace to evolve from a fledgling technology to a commercial business, encouraging energy sector executives to recognize the valuable potential of CCS capability in the emerging low-carbon economy.

Figure 2. Today's global generation mix and future projections.



PPM: Parts per million of carbon dioxide in the atmosphere.

Source: World Energy Outlook 2008 ©OECD/IEA 2008, Annex A, p. 507, as modified by Accenture (UK) Ltd.

Carbon capture and storage

A new technology value chain that allows fossil fuels to be burned nearly free of carbon emissions

A widely accepted definition of CCS is "a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere."[24] CCS is best described through the four elements of its value chain (see Figure 3), namely: capture, transport, storage and monitoring, and a final, optional stage of enhanced oil recovery (EOR).

The following section provides an introduction to this technology value chain.

Capture

This is the initial step of stripping CO_2 from fossil fuels before or after they are burned to produce energy.
Three capture technologies are being piloted, and each has its own nuances and applicability to a specific type of power plant:

- Post-combustion (removal after burning) meets the needs of the standing fleet and is one of the best-understood technologies. This is a key advantage given the small window of time within which CCS needs to reach scale to meet 2050 targets.
- Oxy-fuel (where fuel is burned in pure oxygen) appears promising based on relatively few real-world operational examples. If current pilots are successful, oxy-fuel is likely to compete with post-combustion for the retrofit market.
- Pre-combustion (removal before burning) requires a specific plant type, but has a highly desirable ability to deliver a mix of electricity, hydrogen and low-carbon fuels/feedstock.

Figure 3. Technology summary by value chain segment.

CO_2 capture

Post-combustion

Removes CO_2 from exhaust gas by selective solvents (e.g., monoethanolamine), for pulverized coal plants
Technology: Mature; applicable to all generation types as removal occurs after major plant operation
Economics: Estimate of $47/t$CO_2$

Oxy-fuel

Fuel burned with pure oxygen to produce water vapor and CO_2. Requires capital investment to purchase and integrate the air separation unit.
Technology: Low maturity but progressing for pulverized coal plants
Economics: Estimate of ~$35—$50/tCO_2; more cost competitive than post—combustion. As result of high—efficiency penalty for retrofit, this is likely to be uneconomical for 90 percent of the world's existing stock.

Pre-combustion

Pretreated fuel converted to CO_2 and hydrogen. Combustion requires specific plants that only account for a tiny portion of global capacity (~1.5GW)
Technology: Emerging technology
Economics: Plants more costly without capture (due to the addition of a coal gasification unit) and less costly with capture. Key issue is low penetration; only five IGCC plants built so far for coal-based electricity generation.

CO_2 transport

Shipping

Shipping is suitable for small volumes, or for distances that avoid hilly or mountainous terrain
Technology: Low maturity; 9,000 tCO_2 per year. Parallel experience of shipping hydrocarbons is very mature.
Economics: Competitive if transportation is >1,500 km distance onshore pipeline or >1,000 km offshore pipeline equivalent

Pipeline

Most widely recognized transport solution and presents opportunity to share infrastructure
Technology: Mature; 5,600 km overland pipeline infrastructure globally; in the United States there is capacity to carry 50 MtCO_2 per year and this is set to increase
Economics: Estimate of ~$1—8/t$CO_2$ per 250 km. Competitive for distances <1,500 km, but costs can multiply as result of geographic features

CO_2 storage and monitoring

Depleted oil and gas fields

The most immediate and practical places to store CO_2 because of geological analysis conducted to date
Technology: Mature; enhanced oil recovery (EOR) practiced for more than 30 years in United States
Economics: Estimate of ~$0.5—12/t$CO_2$ for onshore storage (US data), and ~$3.8—$8.1/tCO_2 for offshore storage (European data). Potential for additional revenues through enhanced recovery.

Coal bed seam

Relatively small-scale storage potential and opportunity for enhanced coal bed methane (ECBM)
Technology: Emerging technology; pilots with ECBM recovery under way in Poland, Canada and China
Economics: Estimate of possible negative loss of $20/t$CO_2$ to additional revenue generated from methane recovery for 10 percent of the most favorable sites

Saline aquifers

Storage estimates range from 1,000—10,000GtCO_2 but lack of quality data and chemical understanding
Technology: Mature; industrial scale onshore pilots in Norway
Economics: Estimate of ~$1.9—6.2/t$CO_2$ onshore and offshore of $4.7—12/t$CO_2$ (European data)

Enhanced oil recovery (EOR)

Potential to increase an oilfield's ultimate recovery of oil by 60 percent equating to two decades of additional operation (e.g., Weyburn, Canada)
Technology: Mature; CO_2 EOR is more effective than other tertiary recovery methods such as gas injection but is still only implemented on a small scale due to cost
Economics: Estimate of $10—16 t$CO_2$ for onshore EOR

Sources: Adapted from CO2 Capture and Storage: A Key Carbon Abatement Option ©OECD/IEA 2008, p. 82; referencing Gale, J. and J. Davison (2002), "Transmission of CO_2—Safety and Economic Considerations," Proceedings of the Sixth International Conference on Greenhouse Gas Technologies (GHGT6), Kyoto, Japan; IPCC (2005) "Special Report on Carbon Dioxide Capture and Storage" — p. 30, p. 260, p. 345

Technologies piloted today remove up to 90 percent of CO_2. Those still in the research and development (R&D) stage (chemical looping) have demonstrated the ability to remove 99.5 percent.[25]

Transport

Pressurized CO_2 is most likely to be transported from source to storage via pipeline, although ships could be used for longer distances. CO_2 transport poses some technical and legal challenges, such as negotiating legal rights of passage for laying pipelines. The technology is relatively mature, and there is approximately 5,600 km of overland CO_2 pipeline infrastructure globally. Although technically proven, the existing infrastructure will have to grow substantially to meet the capacity needs for CCS. For example, the United States currently has capacity to carry 50 $MtCO_2$ per year;[26] this represents only 2 percent of annual US carbon emissions from power generation. Additionally, today's infrastructure supports EOR (by taking CO_2 from natural sources[27]) and will therefore have limited reusability for CCS from power generation.

The industry consensus is that transport economics will look more favorable over time as a result of increased demand and network efficiencies. Drawing parallels with similar industries provides a useful range for the anticipated cost reduction; learning effects from the liquefied natural gas (LNG) industry demonstrate a 12 to 14 percent decrease in unit cost for each doubling of capacity.[28]

Storage and monitoring

Storage involves keeping the CO_2 deep underground and monitoring its dispersion. Depleted oil and gas fields (DOGF) that have already undergone extensive geological mapping may be the most immediately practical places to store CO_2. Oil and gas companies have decades of experience storing natural gas deep underground, and the success of these projects offers confidence in the potential to store large quantities of CO_2 for thousands or even millions of years.[29] Apart from using depleted oil and gas fields, other options include saline aquifers (geological formations that consist of porous rocks pocked by tiny holes filled with saltwater, capped by nonporous rocks) and unmineable coal seams. Dr. Tara LaForce, of the Imperial College London's Department of Earth Science and Engineering, describes the potential, saying, "Saline aquifers are in plentiful supply around the world and are often located close to emission sources, making them an ideal resource to store gases deep underground. The storage process involves pumping saltwater containing bubbles of CO_2 through the aquifers. The porous rock acts like a sieve, trapping CO_2."[30] This assessment is echoed by the IEA, who agree saline aquifers are predicted to have several thousand gross tonnage (Gt) of storage capacity.[31] Significant further analysis is required, but if proven to be viable, the world's total storage capacity could be more than sufficient to meet the global population's needs until the beginning of the 22nd century.[32]

Enhanced oil recovery

The final optional, potentially profitable, aspect of the value chain is enhanced oil and gas recovery (EOR/EGR). This is the process of injecting CO_2 into the depleted field to "push" remaining hard-to-access pockets of oil or gas toward producing wells. Commercial EOR operations have increased the life expectancy of a depleted oil and gas field by two decades (for example, Weyburn, Canada[33]).[34] To apply this technique to climate change mitigation, however, will require validation that the CO_2 remains underground.

Technology demonstration

CCS has progressed from R&D to demonstration phase. There are many live demonstration projects around the world today involving manufacturers, major oil players, utilities and governments working together to prove aspects of the CCS value chain (see Figure 4). However, while this technology has been demonstrated in its component parts and on a small scale it has never been tried on a commercial scale and never as the complete process across its value chain.

The Sleipner field in Norway, operated by StatoilHydro, provides one of the largest examples of live CO_2 storage and monitoring. Since 1996, StatoilHydro has removed the excess CO_2 from recovered gas in a tower on its offshore production platform, transporting and injecting it into a saline aquifer 800 meters below the seabed. StatoilHydro has injected about 1 million tons of CO_2 per year, saving $55 million per year in taxes.[35] At Sleipner, StatoilHydro has tried and tested monitoring and verification, and has proved carbon sequestration to be environmentally sound and financially prudent.[36] Other demonstration examples piloting different technology mixes include the In Salah in Algeria, which utilizes a depleted oil and gas field, and Weyburn in Canada, which operates with EOR[37] (see Figure 4 for further examples).

Figure 4. Global top 10 carbon capture and storage demonstration projects.

Project	Location	Stakeholders	CCS value chain focus (see legend)	Fuel type	Technology focus	Power station size	Status
Weyburn	Canada and United States	IEA Greenhouse Gas R&D Program	C, T, S	Injection: CO_2	Storage: EOR	N/A	Operational
Killinghome	United Kingdom	E.ON	C, T, S	Coal; petcoke	Pre-combustion	450MW	Feasibility studies: 2011; Kingsnorth also being considered for post combustion
Callide A	Australia	CS Energy	C, T, S	Coal	Oxy-fuel	30MW	Under construction: 2009
Barry	United States	Southern Company; Mitsubishi Heavy Industry	C, T, S	Coal	Post-combustion; pipeline transport; storage: depleted oil field	25MW	In design; operational 2011
Mountaineer	United States	American Electric Power; Alstom Power; Battelle	C, S	Coal	Post-combustion; storage: geologic reservoirs	200MW	Under construction; operational 2009
Schwarze Pumpe	Germany	Vattenfall	C	Lignite	Oxy-fuel	30MW	Operational
CASTOR Pilot Plant	Denmark	French Petroleum Institute; StatoilHydro; Vattenfall; Alstom Power	C	Coal	Post-combustion	420MW	Operational since late 2005
Hazelwood	Australia	CO_2CRC; CSIRO; Process Group; Victoria Government	C	Lignite	Pre-combustion	200MW	Under construction: 2009
Sleipner	Norway	StatoilHydro	S	Injection: Natural CO_2	Storage: Saline aquifer	N/A	Operational
In Salah	Algeria	BP	S	Injection: Natural CO_2	Storage: Depleted oil and gas fields	N/A	Operational
Fenn Big Valley	Canada	IEA Greenhouse Gas R&D Program	S	Injection: Natural CO_2	Storage: Coal bed seams	N/A	Operational

CCS value chain legend:
C = Capture segment focus
T = Transport segment focus
S = Storage segment focus

Source: Accenture team analysis (2008)

Uncertainties and challenges

Understanding the challenges of building CCS at the requisite scale

The world's dependence on coal should mean that CCS is a vital part of efforts to avoid the catastrophic impacts of climate change. So why doesn't every fossil fuel power station have CCS? Very simply, in addition to the significant cost, a number of uncertainties about this embryonic technology and its environmental impact first need to be resolved.

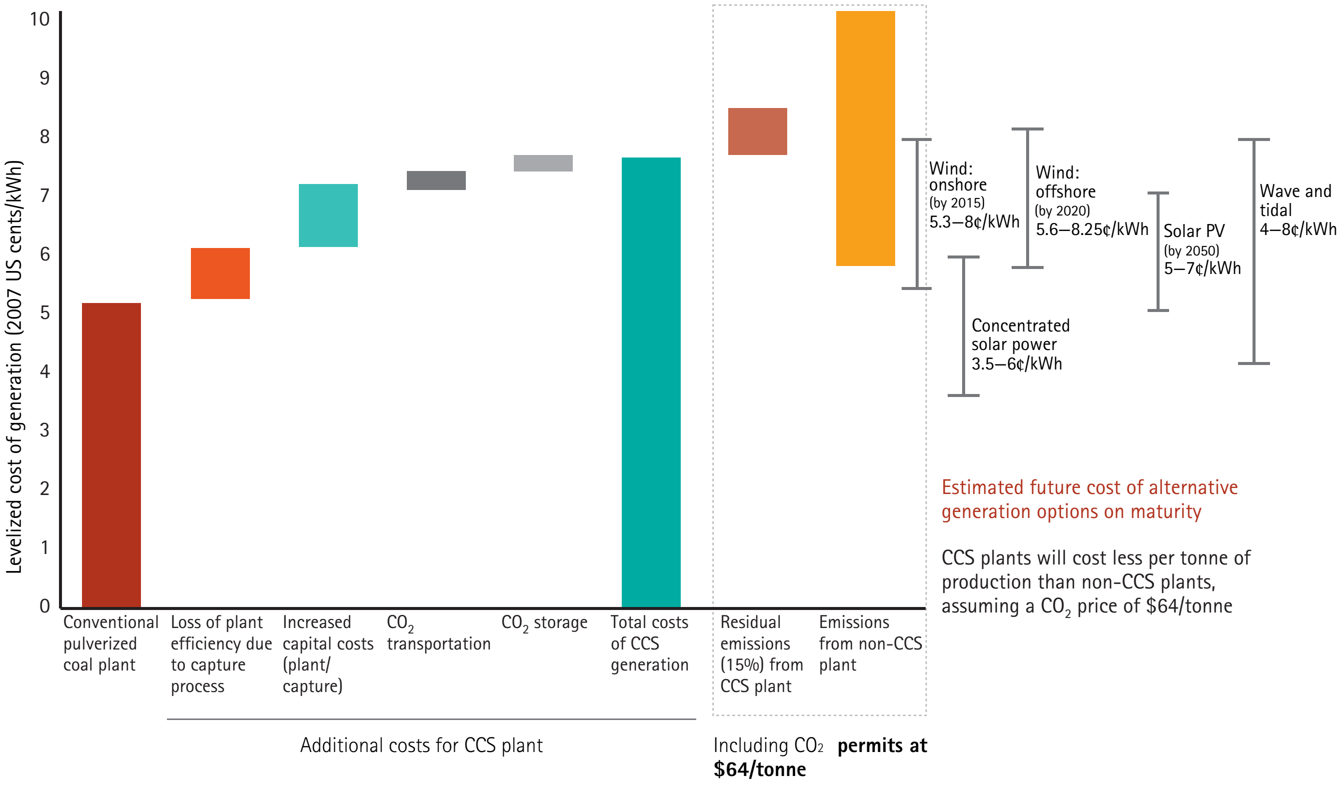
Technology cost and resource requirements

The major challenge holding CCS back is its expense. A majority of the incremental cost of removing CO_2 comes at the capture stage and has two key drivers:

- The increased capital costs of deploying CCS. The basis for capital expenditure is dependent upon the specific capture technology (pre-, post- or oxy-fuel), but broadly it comprises the new assets required to separate the CO_2 from the flue stream and compress it for transport. Initial estimates demonstrate a range of 50 to 100 percent[38] incremental capital cost for adding capture technologies, although the starting point efficiency of the plant and the duration of its remaining useful life, will be an important determinant of the retrofit business case.
- The ongoing thermal efficiency penalties, ranging from 6 to 12 percentage points,[39] have an ongoing operational cost impact. Separation and compression of CO_2 are themselves both energy-intensive processes and result in more fuel being required to achieve the same energy output.

The transport and storage stages contribute further layers of cost. For example, in the case of depleted oil and gas fields, the up-front capping of old extraction wells to avoid leakage will be significant. This results in a total cost estimate for CCS of approximately 8¢/kWh by the UK Committee on Climate Change (for a retrofitted pulverized coal plant, based on 85 percent capture efficiency, from the UK Department of Energy and Climate Change central fossil-fuel price scenario).[40] This is within range of the wave and tidal future projections by the IEA and just slightly higher than the nuclear upper limit of 7.5¢/kWh[41] (see Figure 5).

Figure 5. Carbon capture and storage economics.



Estimated future cost of alternative generation options on maturity

CCS plants will cost less per tonne of production than non-CCS plants, assuming a CO_2 price of $64/tonne

Sources: Adapted from the UK Committee on Climate Change (2008) Building a Low-carbon Economy—The UK's Contribution to Tackling Climate Change—P40 and P49 and Accenture (2008) analysis

Unlike nuclear and renewable technologies—that under optimistic economic scenarios may deliver electricity more cheaply than fossil fuels—adding CCS to fossil fuel plants adds significant cost. It is important to note, however, that CCS is unproven at full commercial scale. That means cost estimates are more uncertain than those for wind or nuclear power. The challenge lies in how that extra cost will be reduced or offset.

Passing on any incremental cost to the consumer is challenging given the competitive nature of energy markets. When consumers pay more for low-carbon electricity, there are important considerations to take into account. Two in particular were highlighted in a recent UK Committee on Climate Change report:

- **Fuel poverty**: The analysis estimated that as a result of meeting carbon budgets, an extra 1.7 million households in the United Kingdom could enter fuel poverty (more than 10 percent of household income required for energy costs) in 2020.[42]
- **Industry competitiveness**: The report also assessed possible impacts of carbon budgets for energy-intensive industry in the United Kingdom. Based on an assessment of energy costs and trade intensity, they conclude a small number of industries may be at risk of "carbon leakage" (that is, the danger that production and/or new investment could be relocated to other countries with less stringent carbon controls).[43]

In addition to the expense, the resources required for CCS also must be considered:

- The US Department of Energy National Energy Technology Laboratory projects that implementation of today's CO_2 capture technologies would significantly increase freshwater consumption by fossil-based power plants.[44] This is likely to pose problems where CCS is implemented in regions where water is scarce. There is also a broader concern regarding global water supplies in a world affected by climate change, and the efficacy or prudence of developing additional industrial processes that depend heavily on water. Unfortunately, the locations with the fastest growing power needs (i.e., China and India) also suffer from water scarcity. Research is focusing on new technologies to reduce the use of water in carbon capture and promises future efficiencies.[45]
- A transport network must be developed for CO_2 and for the large volumes of chemicals (ammonia, amines, carbonates, etc.) required in the carbon capture processes. While there are plans to reuse some existing gas pipelines and leverage efficiencies through yet-to-be-built hub and spoke transport networks, large quantities of steel, concrete, fuels and other materials will be needed for the CO_2 infrastructure build-out. The cumulative emissions resulting from building and operating the required infrastructure, and the extent to which these counteract the emissions reductions achieved through CCS will need to be evaluated.

Long-term storage viability

One of the key questions about CCS is the geological validation of safe and secure long-term storage sites for CO_2. As outlined in the technology section of this paper, there is a reasonable in-principle rationale for the viability of successful and plentiful storage. Theory now has to be tested in practice. This will require both high-level seismological assessments and case-by-case detailed surveys to understand the degree of heterogeneity among reservoirs. There is no empirical method to definitively prove the safety of very long-term CO_2 storage. It is likely that regulatory oversight will be needed to ensure every CO_2 storage site is chosen and operated to minimize the risk of CO_2 leakage into the atmosphere or underground into, for example, drinking water aquifers or operational gas and oil reservoirs. This could occur via man-made potential leakage routes such as abandoned injection wells, adjacent drilling or undetected fractures in the rock formation due to seismic activity. However, the risk of leakage is being addressed through a number of CCS demonstration projects worldwide that are focused on proof of concept for the injection and storage of CO_2 (see Figure 4). EOR has been practiced for more than 30 years in the United States. Coupled with natural gas storage experience, this has provided a level of understanding of how CO_2 behaves when injected into depleted oil and gas fields, and very high trapping rates are seen.[46] Less is known about the chemical reactions and trapping rates in saline aquifers but these are also being explored, for example, through the StatoilHydro Sleipner project.

Legal and regulatory frameworks

CCS technology will only go so far without an effective framework that includes legal and regulatory guidelines, particularly relating to transport and the long-term storage of injected CO_2. To date, there are no uniform guidelines regulating CCS projects nationally or internationally. If regulatory issues are addressed in CCS projects, they are mostly dealt with on a case-by-case basis in project-specific contracts.[47] Such contracts typically only address topics that are necessary to meet existing regulatory requirements and may not cover issues that have yet to be fully resolved, such as liability and safety requirements for long-term storage. This creates uncertainty and confusion about long-term property rights and liability, particularly in the post-injection phases of the project. It also raises concerns about projects' long-term environmental integrity.

In the United States, for example, there is no regulatory framework or precedent to encompass the complexities that must be addressed to implement CCS in any time frame, let alone at the speed and magnitude, which IPPC scientists say we need to.[48] This is a major challenge, perhaps even more complex than the technology itself. Adding to that complexity is the need for international standards and regulatory oversight, which is further necessitated by the anticipated emergence of a cross-border transport infrastructure.

Prior to the construction of an intra-jurisdictional transport infrastructure, CO_2 needs clear and consistent legal classification and clarification of liability issues. A similar issue exists for the long-term legality of storage and exposure for leakage. If the cost reflects the level of uncertainty surrounding storage, liability has the potential to prove a sizable risk for potential operators in this industry.

A call for collaboration

Governments must be galvanized to work with industry to clarify uncertainties during CCS's incubation period

There is an immediate need for government and industry to collaborate in order to work through the uncertainties for this integral carbon mitigation option through financial, regulatory and policy measures.

Making CCS economically attractive

Action is needed to both reduce and offset the cost of CCS. Looking forward, costs are expected to reduce as the technology across the value chain matures, and the effects of economies of scale materialize. But this expectation must be tempered by acknowledging differences in individual coal plants across the generation fleet, which may restrict economies of scale achievable in the capture stage, particularly when retrofitting. So to achieve viable cost reductions, national and international investment in CCS in the next three to five years is critical to changing the economics and finding the technological breakthroughs that will accelerate its commercialization.

So far, the carbon markets have not driven capital decisions, even with mature technologies, and therefore full grants, subsidies and loan guarantees for deployment of a specific technology are the most appropriate levers in this early stage. The European Union and the United States are showing some progress toward the right level of investment. For example, 300 million CO_2 allowances have been allocated under the European Union Greenhouse Gas Emissions Trading System (EU ETS) to stimulate the construction and operation of up to 12 commercial CCS demonstration projects by 2015.[49] Meanwhile the US stimulus bill is expected to help fund more than 10 large-scale projects.[50]

Demands on governments are high, particularly during the present economic downturn. There is a real risk that due to weak balance sheets, CCS funding will not be seen as a priority. That risk has to be mitigated if this technology is to be part of the climate change solution. Governments and policy makers must assess the longer-term societal value proposition for progressing this technology.

Once proof-of-concept is established for CCS, regulatory constructs such as the renewables obligation credits (ROCs)[51] could start to establish value and accelerate uptake. As one of the major technologies to help meet carbon targets, CCS will effectively be the market-making cost structure for any carbon cap and trade scheme in the long term. The economic tipping point will come when it is cheaper for generators to implement CCS than to pay for allowances. However, with the present carbon price at approximately €12/tonne, this prospect seems fairly remote.[52] The third phase of the EU ETS (the auctioning of allocations) and President Obama's intention to establish a cap and trade scheme in the United States will be integral to setting an appropriate carbon price that will allow power generators to meet their targets through CCS.

Validating storage potential

Financial support alone is not enough to secure the success of CCS. We must build a detailed knowledge base of storage options—depleted oil and gas fields and saline aquifers—to understand, on a case-by-case basis, their potential for safely storing millions of tonnes of CO_2. This analysis will require collaboration between a range of partners from business, universities and research facilities. The recent publication, "Opportunities for CO_2 Storage around Scotland," presents a good example of successful research in this area, and is the first fully integrated source-to-store research into CO_2 transportation and storage ever performed in the United Kingdom. The detailed study proves that Scotland's offshore CO_2 storage capacity is comparable with Norway's and greater than those of the Netherlands, Denmark and Germany combined.[53] The US Department of Energy has published a Carbon Sequestration Atlas of the United States and Canada, which provides national and regional perspectives on potential storage locations.[54] Similar studies are required around the globe, applying modeling and engineering techniques to conduct cap rock characterization and better understand onshore and offshore potential storage viability.

Pragmatic and sustainable ways to monitor and verify the safe storage of CO_2 underground over the long-term must be found. There should be a concerted effort to increase demonstration projects focused on safely transporting and storing CO_2, through developing the optimum site monitoring technology and verification techniques.

Effective risk, regulatory and legislative regimes

There is a need to apply a manageable framework to assess and manage risks pre-operation, during operation and long-term post-operation right across the CCS value chain. Best practices developed through demonstration projects should be used to inform such policy decisions. Examples, such as the Offshore Petroleum Amendment (Greenhouse Gas Storage) Bill introduced by the Australian government in 2008 to deal with liability of transport and storage, represents one country's major steps forward in this area.[55] The key will be the translation of such national efforts into a global standardized methodology. Bodies such as the Carbon Sequestration Leadership Forum and their collaboration with the International Energy Agency are working toward establishing global standards for managing risk and liability. It is important not to underestimate the need for national or international political oversight to coordinate such huge infrastructure investments and implementation efforts.

Building public awareness

A key imperative of industry, governments and nongovernmental organizations will be to build public awareness and acceptance of this technology and its investment requirements, and to acknowledge the risks. Although awareness of the concept of "clean coal" has likely increased over the past few years, public understanding of the technologies and their implications remains low. Specific geographic issues also must be accounted for when seeking public acceptance, as in the United States where sensitivities about storage are expected to be greater (as much of the storage capacity is underneath inhabited land). Australia's Centre for Low Emission Technology and the European Union's ACCSEPT project (Acceptance of CO_2 Capture, Storage Economics, Policy and Technology) are good examples of collaborative partnerships between universities, government and industry to increase public awareness. But more must be done, as public acceptance of the large-scale infrastructure, its benefits and risks are critically important for accelerated technology adoption.

Carbon capture and storage market evolution

Assuming the technical and regulatory uncertainties are addressed, the market will be launched in Europe, North America and Australia and will evolve over three horizons–from demonstration to global commercialization

Once industry and governments work through the uncertainties previously described, they need to act decisively and commit to this technology to drive out costs as rapidly as possible and capitalize on ways to make CCS attractive. Accenture views CCS as a commercial opportunity. Assuming financial and regulatory constructs are in place, CCS capabilities will become market-relevant, sought-after assets, placing a company and/or country at the forefront of a technology that could cut carbon emissions across the world.

Accenture expects the CCS market to evolve over three horizons, marked by regulatory, economic and technological tipping points. The evolutionary direction will be driven by practical and political consideration, namely: the types of emissions sources and their geographic location relative to viable storage sites, characteristics of the standing fleet such as age, and the favorability of local regulatory and legislative regimes.

Although Europe, North America and Australia are expected to lead this development, there is a need to accelerate investment now to support a rapid market evolution to Horizon 3 in order to address the majority of the world's CO_2 emissions from coal in China and India. It cannot be discounted that regulatory structures in China, paired with its more acute national pollution threats, could see China accelerating beyond Western development and becoming an early adopter of CCS.

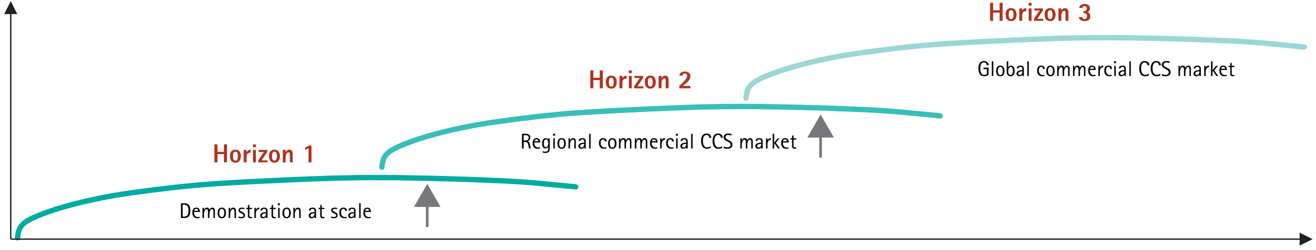
Horizon 1

The initial horizon will focus on power generators in Europe, North America and Australia, owing to the increasingly favorable legislative regimes and relatively high geographic co-location between emitters and potential storage sites. In Europe and North America, approximately 95 percent of the largest stationary emitters are within 500 km of such storage sites, compared with just 60 percent in China and India.[56] Moreover, within Europe, a significant portion of potential storage capacity is made up of depleted oil and gas fields that have the added potential for EOR. The objective will be demonstration at scale. This stage will primarily be funded by governments through grants, loan guarantees and tax relief, and will support the current EU goal for 12 demonstration projects to be live by 2015[57] and potentially 10 in the United States.[58] As an embryonic phase, it will also lead to the creation of appropriate CCS-specific legislative and regulatory frameworks that can be rolled out to other regions.

Horizon 2

The second horizon marks the transition from CCS demonstration to commercialization, whereby regional cap and trade schemes establish a sufficient value for carbon, providing an economic incentive to store rather than emit. This tipping point denotes the evolution from CCS as a technology to CCS as a marketplace, with tangible methods for extracting value by avoiding costs and generating revenues. The employment of investment analytics to preempt the approximate timing of this tipping point with adequate lead-time to build skills will be key in determining a company's ability to tap this CCS market potential, as described further in our next section.

Figure 6. Carbon capture and storage market horizons.



Horizon 1 to Horizon 2 tipping points

- Kyoto II and mandatory cap and trade in North America, Europe
- CCS regulatory framework and standards established
- Successful demonstration at scale (300 MW)
- End-to-end value chains established
- North America, Europe value of abatement will begin to make CCS commercially viable on a regional basis

Horizon 2 to Horizon 3 tipping points

- CDM or similar, subsidize CCS uptake in China and India
- Global uptake of emission-reductions targets including China and India
- Capture technology learning and innovation delivers considerable improvements in CCS effectiveness
- India and China value of abatement will begin to make CCS commercially viable on a global basis

	Horizon 1	Horizon 2	Horizon 3
Regions	• 1º Tier: North America, Europe, Australia	• 1º Tier: North America, Europe • 2º Tier: Japan	• 1º Tier: India and China • 2º Tier: Rest of world
Regulatory	• Tax relief for enhanced oil recovery • National/regional CCS competitions and policy frameworks to support CCS	• Growth of regional carbon markets with full auctioning of allowances • Emissions standards on power plants	• Established global carbon market • A regulated industry emerges for CO_2 transport
Technology	• EOR continues to prove transport/storage • Range of capture technologies piloted • Shipping and pipeline transport options developed • Focus on storage in DOGF	• Competing capture technologies • Continued capture R&D efforts • Scaled transport infrastructure • Focus on DOGF, increase in saline aquifers	• Increased uptake of new build capture technologies in North America and Europe, retrofit opportunities in India and China • Scaled and increasingly intercontinental transport infrastructure • Transition to saline aquifers
Economics	• Cost of CCS > market value of abatement • Projects government sponsored	• Cost of CCS ~ market value of abatement • North America and EU private enterprise, India and China, government sponsored	• Cost of CCS < market value of abatement • Private enterprise funded

Source: Accenture team analysis (2008)

Figure 7. Carbon capture and storage value chain and viable business models.

CO_2 source
Technology provider
Installation of technology kit
Design of infrastructure
Compression providers
Operation and maintenance

Infrastructure developer
Infrastructure owner
Infrastructure operator
Infrastructure maintenance
Liabilities trading
CO_2 injection

Storage site identifier
Site consenter
Site leaser
Site developer
Monitoring technology provider
Insurance

Capture specialist
Sell, install and license capture technology for use by emitters.

Pressurization and transport services
Investment in infrastructure followed by charging for third party rights to access.

Early investment in hubs can prove highly profitable in the future; potential for multiple customers to one distribution network if scale is sufficient.

Secure, lease and monitor storage capacity
Specialists storing carbon for emitters in a variety of locations in addition to maintaining security of CO_2 to minimize any potential leakage.

Potential private service to the government for monitoring storage sites and local environment.

Enhanced oil recovery
Specialists who utilize CO_2 in depleted oil and gas fields for use of enhanced oil or coal bed methane recovery.

As technology improves and price of oil rises, this is expected to become more economically viable.

Source: Accenture team analysis (2008)

Accenture foresees several opportunities for creating viable business models within the new CCS value chain, including:

CCS service provider

End-to-end emissions-management service provision, whereby the third-party is responsible for the capture, transport and secure storage of an emitter's CO_2 at a value relative to the value of emissions—in many cases this value equals hundreds of millions of dollars in Europe already.

Transport infrastructure provider

The offering of third-party access to a rail and/or pipeline infrastructure on a \$/tonne CO_2 transported basis. An investor could gain first-mover advantage by developing trunk infrastructure to support a power generation cluster and realize major economies of scale.

Enhanced oil recovery specialist

A service targeted at oil companies with the ability to provide CO_2 to depleted oil and gas fields in order to increase the company's ability to recover oil.

Within this emerging CCS marketplace, we expect to see technological improvements, learning effects and economies of scale—all of which reduce the cost of implementing CCS. Notable cost advantages are also likely to be realized from cluster development and shared infrastructure; that is, through the targeting of heavy industrial geographic regions, such as the Ruhr region in Germany.

As well as new business opportunities, the second horizon will encompass regulatory mechanisms that help share the CCS capabilities gathered in the developed world with the developing world, for example, via the Clean Development Mechanism or its successor. Today, outside of Europe, North America and Australia, the developing economies remain predominantly spectators to the clean-technology revolution. But with China alone building an average of one new coal-fired power station every four days in 2006, developing countries will become the CCS customer base for the future.[59]

Horizon 3

The third and final horizon marks CCS's progression from regional to global phenomenon, whereby early adopter countries successfully transfer their knowledge, global regulatory frameworks place value on carbon and the developing world economies deploy the technology at mass scale. This horizon will also see the full range of storage options being put to use, with the increased uptake of saline aquifers, as geologists and seismologists identify the locations and capacity for the highest potential aquifers and with the gradual depletion of EOR opportunities. At this key stage, the impact on global emissions will be a dramatic improvement.

Implications for utility and energy companies

Action is required now to position for high performance in the low-carbon economy

Energy players with considerable investment in coal and gas-fired power will need to embrace CCS or develop other plans to decarbonize the power they provide. While regulation for different low-carbon technologies may take some time to fully develop, a more concerted focus on demonstration projects now (testing all technology options and stages of the value chain) will accelerate the realization of learning and scale effects. Governments and regulators have a responsibility to establish the environments that are conducive to that aim.

Companies need to approach CCS with a commercial mind-set, ensuring they view it not only as technology that is growing in importance, but also as an emerging marketplace in which there will be winners and losers, buyers and sellers, and they need to have a clear strategy for participation. Companies also must be open to collaboration across the energy industry. CCS will unite the generation knowledge and assets of utilities with the exploration and production skills and capabilities of the upstream oil sector.

Determining the timing and value of investment in CCS is a complex decision. When making these multi-faceted decisions, industry leaders would benefit from employing innovative investment evaluation techniques. Standard discounted cash-flow analyses can be less informative in highly volatile and capital-intensive contexts, driving managers to look for ways to trade off lower investment costs to drive a more positive net present value. Industry leaders should be aware of the unique context and apply appropriate decision-support tools. A more flexible approach could be real-option analysis, which allows the decision maker to chart a decision tree, building in tipping points at which the merits of an investment can be reevaluated to take into account changes such as a shift in carbon price and/or CCS demand.

For utility and energy companies to achieve high performance in the low-carbon economy, Accenture recommends:

Conduct an internal review of carbon exposure and examine a range of low-carbon technology alternatives

Energy sector players need to evaluate the potential impacts of carbon cost on their profitability. They will need to bring together their emissions levels, future generation strategy, the geographic distribution of assets and the regulatory environments they conduct business within, to understand the potential impact of CO_2 on their business. As part of this analysis they should evaluate CCS in the context of other low-emitting alternative technologies and determine which approach sits best with their corporate strategy. Those players with limited exposure also can identify how they can maximize their competitive advantage.

Understand CCS capability and potential partners

Those companies with significant carbon exposure will benefit from establishing a baseline of CCS capability: for example, identifying their proximity to suitable storage locations and assessing the level of awareness and acceptance of CCS within their organization. Utilities and other power generators also will benefit from identifying other energy companies with complementary skills, assets and synergistic interests for investing in CCS.

Help shape CCS regulatory and financial constructs

Energy players should leverage their ability to influence government and regulators to help drive the CCS agenda and ensure there is sufficient support for this technology. For example, within the United Kingdom, players should engage with the Department of Energy and Climate Change to urge the acceleration of the national CCS competition and encourage the development of alternative funding mechanisms.

Employ appropriate tools to aid CCS investment decision making

Energy players should seek to use analytical investment tools that take account of the element of technology risk: for example, to identify the optimum timing and degree of investment, which can give them a foothold in the game when the technology and regulatory tipping points play out.

Invest and learn

Businesses should look for opportunities to lead or participate in CCS pilots and demonstration projects to help advance the technology, build internal knowledge and capabilities, and to identify potential business opportunities as the markets evolve.

Maintain a watch on CCS tipping points

High-performance businesses, specifically power generators, should monitor the changing CCS regulatory environment—understanding the outcomes of the discussions in preparation for the United Nations Climate Change Conference (COP15) and any important new policy decisions, as well as tracking the latest CCS technology advancements—to ensure they remain receptive and agile to changing conditions.

The transition to a new energy era is extremely challenging, and fossil fuels will be part of the energy mix for a long time to come. CCS represents a valuable bridging solution to allow societies to rapidly reduce harmful GHG emissions while growing a base of alternative generation options. The challenges of CCS are not insurmountable, but will require a tenacious, coordinated approach—one that is orders of magnitude larger and faster than current progress. It is imperative that governments and industry alike ensure they are investing in the technology solutions that will help organizations manage this transition. Countries that act now to incubate CCS will enhance their ability to emerge from the downturn with a broad–based functioning industry. Further, they could take a leading role in a critical area of technology and political innovation on the journey to high performance in the low–carbon economy.

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The Accenture Climate Change practice

Accenture's Climate Change practice is a global practice within the Resources operating group formed to help our clients in the utilities, energy, chemicals and natural resources (forest products, building products, metals and mining) industries address the opportunities and challenges resulting from climate change to achieve high performance in the global move to a low-carbon economy.

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