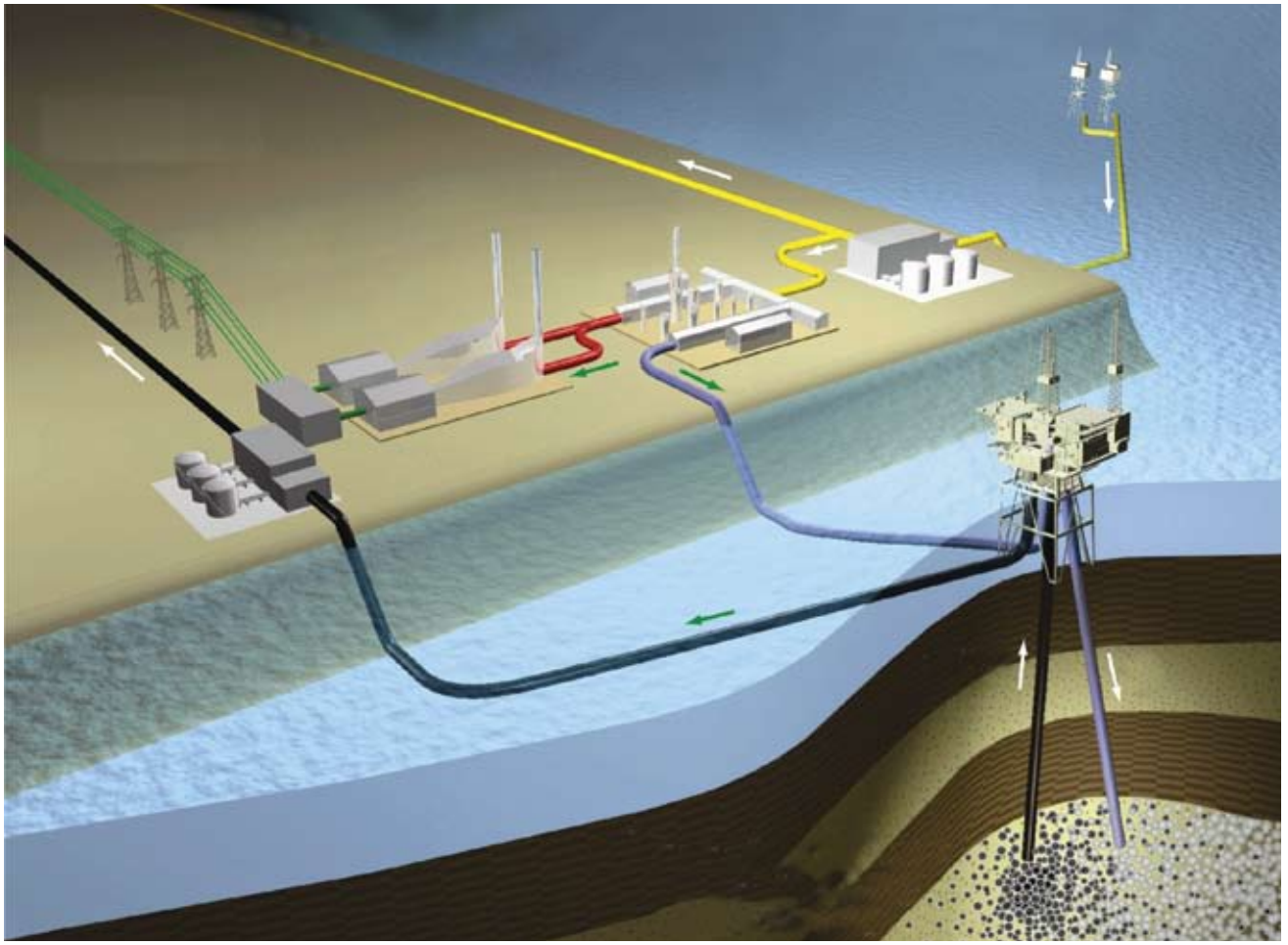

二氧化碳能够注入石油和天然气油田，提高产量。英国石油公司
CO_2 can be injected into oil and gas fields to boost production. BP.

投资二氧化碳清洁项目

据估计，至2100年，碳捕集和储存将占全球碳减排总量的10%至55%，但是目前储存仍然处在起步阶段

Investing in cleaning up CO_2

It is estimated that carbon capture and storage will account for between 10 and 55 per cent of the total carbon mitigation efforts until year 2100, although storage is still in its infancy

巨大的石油、天然气和煤炭矿藏经历了数亿年的沉积，但是在地质沉积相对较短的时间内就得到了开采和燃烧。政府间气候变化专门委员会的报告称，矿石燃料产生的二氧化碳快速排放已经造成了大气中二氧化碳的积聚。

IPCC的分析表明，没有任何一项技术能够单独实现所需的二氧化碳减排，这一目标的实现需要运用各种措施。这些方案包括提高

Vast deposits of oil, gas and coal that took hundreds of millions of years to accumulate are being extracted and burned in the geological blink of an eye. According to the Intergovernmental Panel on Climate Change (IPCC), the rapid release of carbon dioxide (CO_2) from the combustion of fossil fuels has led to a build-up in the atmosphere.

能效、转向碳密集度更低的燃料、可再生能源和降低非二氧化碳温室气体的排放。但是，碳捕集和储存(CCS)技术可以实现从矿石燃料的平稳过渡，同时有助于降低环境压力。

日益增长的投资

CCS(也称为碳捕集和封存或清洁煤炭技术)包括捕集二氧化碳、防止温室气体排入大气以及将其储存到较深的地底。据IPCC预计，到2100年前CCS可能达到全球碳减排总量的10%至55%。

随着示范项目规划的启动，CCS战略正逐渐在欧盟和北美发展起来。IEA称，已经规划了约15个采用CCS的发电厂，而另外7个CSS项目也提上了议程。

2008年2月，一个政府授权的专门小组建议加拿大政府投资20亿美元(合人民币140亿元)以推动CCS技术的发展，并计划在2015年前帮助该行业建成3至5个可运行的项目。欧盟承诺在2014年前投资90亿美元(合人民币640亿元)用于相关能源的研究。其中大部分资金将用于CCS技术的，以在欧洲修建12个相应的工厂。

环境影响

二氧化碳向环境中的快速排放正在影响着发电厂的发展和水资源的利用，造成海洋酸化。更重要的是，它造成了大气中固结太阳能方式的失衡。

Analysis by the IPCC indicates that no single technology option will be able to achieve the required reductions in CO_2 emissions; rather a portfolio of measures will be needed. Options include energy efficiency improvements, the switch to less carbon-intensive fuels, renewable energy sources, and reduction of non-CO_2 greenhouse gas emissions. However, carbon capture and storage (CCS) technologies may allow a smoother transition away from fossil fuels, while at the same time helping to reduce the environmental pressures.

Increasing investment

CCS (also known as carbon capture and sequestration or clean-coal technology) involves capturing the CO_2, preventing the greenhouse gas entering the atmosphere, and storing it deep underground. The IPCC estimates that the potential of CCS could be between 10 per cent and 55 per cent of the total carbon mitigation efforts until year 2100.

CCS strategies are slowly gaining momentum in both EU and North America as plans for demonstration projects are set in motion. According to the IEA around 15 power plants with CCS are being planned and another seven CCS projects are on the drawing board.

高油价已将能源行业的目光转向煤炭
High oil prices have turned the power industry towards coal

随着油价飙升至前所未有的高度，人们的目光开始从石油转向煤炭，而后者排放的二氧化碳密度更高。尽管燃煤发电厂的效率正在提高，但是二氧化碳排放仍然是个问题。

除了上述市场动态因素外，巴西、俄罗斯、印度和中国等国的石油需求在近年来已飞速提升。国际能源机构(IEA)称，美国和印度成为二氧化碳排放量最大的国家。

据麦肯锡最近的一项报告表明，通过有效改进，在未来的15年内全球二氧化碳的排放有可能降低50%。如果政策制定者和企业能够达到此种效率，这将大大有利于环境的发展。但是，就目前看来，这种突然和快速地提升能源生产率的可能性极小。

In February 2008, a government-commissioned panel recommended that Canadian governments should spend USD 2bn (RMB 14bn) to encourage CCS and help the industry get three to five projects operational by 2015. The EU has pledged to invest USD 9 bn (RMB 64bn) on energy-related research by 2014. Much would be devoted to CCS to build 12 plants across Europe.

Effects on the environment

The rapid release of CO_2 into the environment is affecting how plants grow and use water, causing the oceans to acidify and, most importantly, causing an imbalance in the manner by which solar energy is trapped in the atmosphere.

While the oil price is surging to all-time highs, utilities switch from oil to coal, which is even more CO_2 intensive. Despite the improving efficiency of coal-fired power stations, CO_2 emissions remain a problem.

In addition to these market dynamics, oil demand from countries including Brazil, Russia and India, China has been soaring in recent years. According to the International Energy Agency (IEA), the US and India are among the biggest emitters of CO_2.

A recent study by McKinsey shows that global CO_2 emissions could potentially be reduced by 50 per cent in the next 15 years through efficiency improvements. If policy makers and firms could produce such efficiency gains, this would yield significant environmental benefits. At present, however, such a sudden and rapid improvement in energy productivity seems rather unlikely.

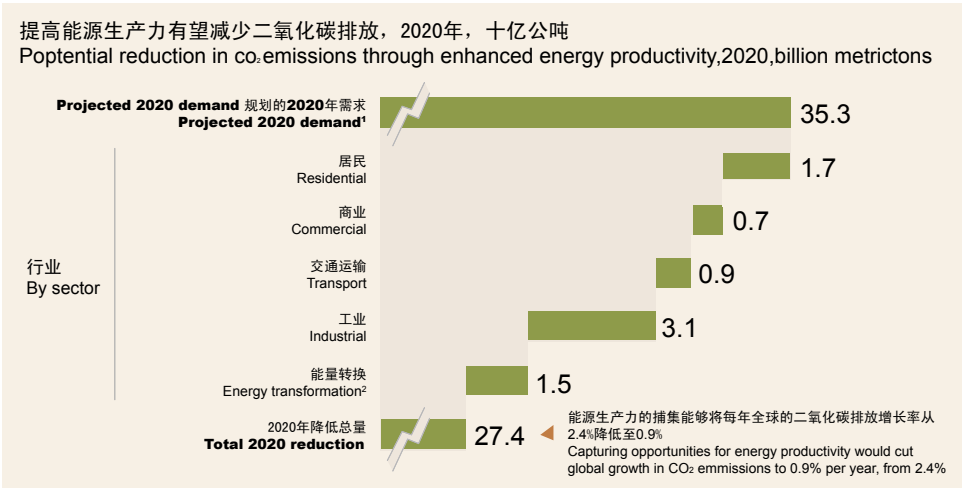

图1 – 更高的生产率，更低的排放(来源：麦肯锡全球研究院)
Figure1 – Better productivity, fewer emissions(Source: McKinsey Global Institute)

Capture and storage

Large-scale capture of CO_2 from fossil-fuel power plants is fairly developed, and CO_2 emissions can be reduced by up to 90 per cent, depending on plant type. But the storage of CO_2 is still in its infancy and is controversial.

Various approaches for CCS have been developed and have proved to be technically feasible. However, they have yet to be made available on a large-scale commercial basis.

These are the three ways to store CO_2 underground. Firstly, CO_2 pumped into unused coal fields displaces methane which can be used as fuel. Secondly, CO_2 pumped into and stored safely in saline aquifers that are

捕集和储存

化石燃料发电厂大规模捕集二氧化碳已经得到了很大发展，发电厂类型不同，降低二氧化碳的排放最高可达90%。但是二氧化碳的捕集仍然处于起步阶段，并且存在诸多争议。

CCS的各种方案已经开发，并且其技术可行性也得到了验证。但是，它们还需要投入大规模的商业运用。

目前有三种方法可以将二氧化碳储存在地下。第一种是将二氧化碳泵入未开采的煤田，替换能够用作燃料的甲烷。第二种是将二氧化碳泵入并安全储存在盐水含水层中，在这个地层内包含多个含水的地下岩石层和盐层。第三种是将二氧化碳泵入油田内，帮助其保持压力，使开采更为便利。

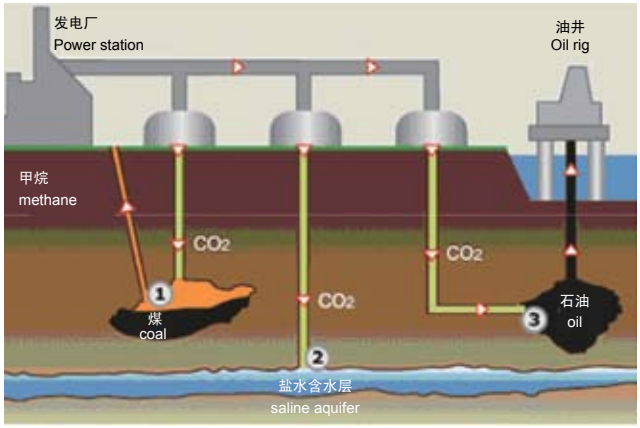

图2 – 碳捕集和储存的选择方案(来源：世界煤炭研究所)
Figure2 – Options for carbon capture and storage (Source: World Coal Institute)

二氧化碳在地层(例如枯竭的石油天然气油田和含水层)的地质储存被认可具有可控制的环境影响，但是仍然需要进行深入研究，以阐明这个问题。二氧化碳在深海的储存是一种对环境有着较大潜在影响的选择方案。

在深海储存中，存在大幅提高海洋酸化的风险，这个问题也源自于大气和海洋中现有的过多二氧化碳含量。而深海储存中二氧化碳的保持将依赖于深度。IPCC预计，在1,000至3,000米的深度处，30%至85%二氧化碳将能够保持500年以上。

根据挪威Sleipner气田的一项环境评估，在运行十年后，地质存储是永久储存二氧化碳最明确的途径。在加拿大的Weyburn项目中，5,000年后已储存的二氧化碳其释放的可能性预计低于1%。

目前，地质岩层被认为是最具有前景的储存位置，并且没有泄漏危险。对于精心选择、设计和管理的地质存储场所，IPCC预计二氧化碳将能够保持数百万年，并且这些场所在二氧化碳注入1,000多年后有可能达到99%的保持率。

CSS面临的主要挑战

第一个挑战是处于开发阶段的储存技术，需要对其进行更多地研发，以确保二氧化碳储存能够可靠的运行于基层上。此外，二氧化碳封存后碳是否能够安全长期地存储在地下，及其远距离运输(如同天然气)是否经济可行，这都没有得到验证。

underground layers of rock and salt that contain water. Thirdly, CO_2 pumped into oil fields helps to maintain pressure, making extraction easier.

Geological storage of CO_2 in underground formations like depleted oil and gas fields and aquifers is believed to have manageable environmental impacts, although further research is needed to clarify this issue. Storage of CO_2 in the deep ocean is an option with potentially high environmental impacts.

In the case of deep ocean storage, there is a risk of greatly increasing the problem of ocean acidification, a problem that also stems from the excess of CO_2 already in the atmosphere and oceans. For ocean storage, the retention of CO_2 would depend on the depth. The IPCC estimates 30 to 85 per cent would be retained after 500 years for depths of 1,000 to 3,000m.

According to an environmental assessment of Norway's Sleipner gas field, conducted after ten years of operation, geological storage is the most definite way to store CO_2 permanently. At the Weyburn project in Canada, the likelihood of a release of stored CO_2 has been estimated at less than one per cent in 5,000 years.

Geological formations are currently considered the most promising storage sites and do not have leakage risks. For well-selected, designed and managed geological storage sites, the IPCC estimates that CO_2 could be trapped for millions of years, and that the sites are likely to retain over 99 per cent of the injected CO_2 over 1,000 years.

Major challenges facing CCS

The first challenge is the storage technology, which is still in a development phase and will require more research and development (R&D) to ensure that CO_2 storage can run reliably on baseload. In addition, it is unproven that once sequestered, carbon can be stored safely and indefinitely underground or that it can be transported economically over large distances, as is natural gas.

The second is getting policy makers to put in place the necessary legislative framework and allow the building of CCS projects as well as new pipeline technologies. A major step was the amendment of the 1996 London protocol on dumping waste at sea to allow CCS at sea. According to the European Environment Agency (EEA), big new markets need bold policy measures to exploit policy changes. Putting a tax on CO_2 could make a difference.

The third challenge is cost. At present, academics estimate that, for CCS to be viable, there needs to be a carbon tax of at least USD 45 (RMB 320) per ton. The Norwegian Statoil started CCS under the sea in 1997, stimulated by Norway's tough carbon tax – which now stands at USD 75 (RMB 533) per ton. Swedish utility Vattenfall estimates the break-even cost at USD 30-45 (RMB 213-320) per ton, of which around two-thirds is

挪威Sleipner油田每年处理约100万吨二氧化碳
Norway's Sleipner field disposes of about 1m tons of CO_2 a year

第二个挑战是政策制定者制定必需的立法框架，确保CSS项目和新管道技术的实现。1996年伦敦对海洋倾倒污染物协议的修订就是一个重大的进步，从而使CSS能够应用于海洋。欧洲环境署(EEA)称，新兴大市场需要采取大胆的政策措施，应对政策进行修订。并表示对二氧化碳征税很重要。

第三个挑战是成本。目前，经济学家估计，直至CCS经济可行为止，每吨碳税将至少需要45美元(合人民币320元)。挪威Statoil在挪威严格的碳税政策(如今已达每吨75美元(合人民币533元)刺激下，于1997年启动海下的CCS项目。瑞典公共机构Vattenfall估计，碳税的平衡成本为每吨30至45吨(人民币213至320元)，其中约三分之二的投资用于捕集，其余用于运输和储存。但是下第二年的成本可能会降低，随着各项技术的商业化，这种情况通常都会发生。

令人惊讶的是，在欧盟排放贸易方案下，鼓励各公司采用CCS，因为地下储存的碳不需要二氧化碳许可证。但是仅靠排放贸易是无法实现其经济性的，因为捕集和储存设备的建造费用预计将提高发电厂30%至70%的建造成本。

大规模的CCS项目

2007年，有四个工业规模的储存项目在运行。Sleipner是历史最悠久的项目，它修建于1996年，位于北海，在这里挪威StatoilHydro公司从天然气内清除二氧化碳，并处理深层盐水含水层的二氧化碳。自1996年，Sleipner每年储存约100万吨二氧化碳。第二个项目是位于巴伦支海的Snøhvit气田，年储存70万吨。

Weyburn项目是目前世界上最大的CCS项目。它启动于2000年，位于1954年加拿大萨斯喀彻温省的东南部Weyburn开采的一个油田。第一个阶段于2004年完成，并且表明二氧化碳能够安全和长期地储存在地下。第二个阶段预计将持续至2009年，目前正在研究如何将这项技术展至更大规模。

第四个场所位于In Salah，如同Sleipner和Snøhvit一样，它是阿尔及利亚的一个天然气储层。二氧化碳从天然气中分离，并以每年120万吨的速度注入地下。

尽管二氧化碳已经成功储存在北海下，但目前还没有CSS设施应用于发电厂。IPCC预计，如果采用CCS技术，将能够降低发电厂约80%至90%的二氧化碳排放。

2003年美国政府宣布了FutureGen项目——采用CCS技术的275MW试验性零排放燃煤发电厂。但是，美国能源署决定在2008年1月调整该项目，耗资18亿美元(合人民币128亿)修建几个更小的试验性项目，深入进行更多试验。

invested in capture, and the remainder to transport and storage. But the costs may be reduced over the next years, because that is generally what happens as technologies are commercialised.

Surprisingly, under the EU's emissions trading scheme, companies will be encouraged to make use of CCS, as the carbon stored underground would not require CO_2 permits. But emissions trading alone will not be sufficient to make CCS economical, as building capture and storage facilities are forecast to add 30 to 70 per cent to the cost of building a power plant.

Large-scale CCS projects

As of 2007, four industrial-scale storage projects are in operation. Sleipner is the oldest project, being built in 1996, and is located in the North Sea where Norway's StatoilHydro strips CO_2 from natural gas and disposes of the CO_2 in a deep saline aquifer. Since 1996, Sleipner has stored about 1m tons CO_2 a year. A second project in the Snøhvit gas field in the Barents Sea stores 700,000 tons per year.

The Weyburn project is currently the world's largest CCS project. Started in 2000, Weyburn is located on an oil reservoir discovered in 1954 in Weyburn, southeastern Saskatchewan, Canada. The first phase finished in 2004, and demonstrated that CO_2 can be stored underground at the site safely and indefinitely. The second phase, expected to last until 2009, is investigating how the technology can be expanded on a larger scale.

丰富的煤炭蕴藏本身也是推行切实可行的CCS的驱动因素
The plenitude of coal is in itself a driver for pursuing workable CCS

目前大多数CCS技术可用于发电厂，但是仍需要大规模的示范项目
Most of the technologies for CCS are available for power plants, but demonstration projects are still needed on a large enough scale

展望未来

斯特恩报告(2006)和最近的政府间气候变化专门委员会报告(2007)均得出这样的结论：大量证据表明，气候变化是一个非常严重而紧急的问题。碳降低技术(包括CSS)将在应对全球气候变化进行技术变革中起到关键作用。

表面上看，如果是化石燃料特别是蕴藏丰富的煤炭，没有大量二氧化碳排放至大气产生危害，那么CSS技术对其利用仍然很有前景。尽管CCS技术所需的大多数技术都已经具备，但大规模应用CCS技术仍需要示范性电厂。

根据JPMorgan进行的研究，这项技术展示了一种解决当前问题的长期解决方案。它的研究表明，这项技术远未成熟，要实现高可靠性和经济可行性，仍然需要多年的发展。CSS技术的广泛采用将依赖于解决技术问题和相对较高的碳排放价格(参见图3) ——这将使该技术经济可行。

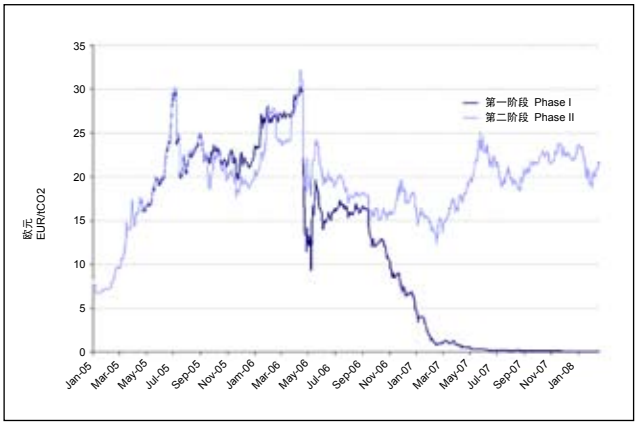

图3 – 欧盟排放贸易方案下的碳价格(来源：新碳金融部)
Figure3 – Carbon price under EU emission trading scheme (Source: New Carbon Finance)

对用于更廉价电力生产的化石燃料需求持续增长。尽管经济形势错综复杂，但蕴藏丰富、碳密集的煤炭已成为推行CCS的一个论题。这是一种重要的长期解决方案，以应对气候变化，并将其转向更为持续的能源生产。

本文由Mora Associates Ltd.(www.moraassociates.com)分析师Leonard Wagner撰写

The fourth site is in In Salah, which like Sleipner and Snøhvit, is a natural gas reservoir located in Algeria. The CO_2 will be separated from the natural gas and re-injected into the subsurface at a rate of about 1.2m tons per year.

Although CO_2 has been stored successfully under the North Sea, there are no CCS facilities currently attached to power plants. The IPCC estimates that some 80 to 90 per cent of the CO_2 emissions from a plant without CCS can be avoided.

In 2003 the US government announced the FutureGen project – 275MW pilot zero-emission coal-fired power plant using CCS technology. However, the US department of energy decided in January 2008 to restructure the project and spend USD 1.8bn (RMB 12.8bn) to build several smaller pilot projects and do more extensive trials.

Looking to the future

The Stern Review (2006) and a recent IPCC report (2007) have both concluded that there is overwhelming evidence showing that climate change is a serious and urgent issue. Carbon abatement technologies, including CCS, will play vital roles in revolutionising techniques for combating global climate change.

At first glance, CCS holds the promise of continuing to use fossil fuels, especially coal because of its abundant reserves, without the harmful consequences of large amounts of CO_2 entering into the atmosphere. However, while most of the technologies needed for CCS are available, demonstration plants are still needed before CCS can be implemented on a large enough scale.

According to research conducted by JPMorgan, the technology presents a distant long-term solution for today's problems. Its study shows that the technology is far from being mature and may need years to become reliable and commercially viable. The widespread adoption of CCS will depend on both resolving technological issues and relatively high carbon emission prices (see figure 3) – which would make the technology economical.

There is a continued rising demand of fossil fuels for cheap power generation. Despite the tricky economics, sheer abundance of carbon-intensive coal is an argument for pursuing CCS. It is an important long-term solution to tackle climate change and move towards greater sustainability in energy production. ■

This article was written by Leonard Wagner, analyst at Mora Associates Ltd., www.moraassociates.com