Technology change as a source of carbon emission abatement

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Notes: Huge topic. Extensively discussed in Stern report among others. Now uncontentious to say low carbon technologies will contribute to reducing carbon emissions compared to a plausible BAU. This is true of renewable energy in electricity generation, various forms of low carbon vehicles, more energy efficient boilers in homes. The three main unresolved issues are speed to market of backstop technologies, points at which they becoming economically viable with or without a correctly priced value of carbon and the role of government. In terms of economics little is new. The issues are establishing the correct incentives including the detail that leads to wait and see, understanding the process of adoption and diffusion of low carbon technologies in sectors characterised by high fixed and sunk costs in specific technologies that combine to lock old technologies in and keep newer lower carbon ones out and relating analysis to policy.

Main Question

Does Carbon Capture and Storage technology provide a large part of the economic efficient solution to reducing CO_2 emissions in China?

Notes: In principle CCS can also be applied to energy intensive process industries e.g cement. Steel. Aluminum. Benefits not only china but also US and India who are also heavily reliant on coal fired power stations for power generation.

Talk structure

CCS as backstop technology

- Mainly in electricity generation
- Essential characteristics
- Application to China
- Problem of wait and see
- Adoption and diffusion

Concluding observations

Carbon Capture and Storage

- IEA estimates CCS could contribute 28% to carbon reduction by 2050
- Post or pre combustion
- Separation; carbon from other gases
- Processing
- Compression, and distribution;
- Storage impermeable rock.

Notes: Lowest costs of separation among fuel types emitting highest concentrations of carbon. I.e pure CO_2.

The International Energy Agency (IEA) estimated that CCS could contribute up to 28% of global carbon dioxide mitigation by 2050, whilst the Stern Review estimates that to limit global warming to +2˚C without CCS will increase costs by more than 60%.

There are three basic methods for capturing CO_2 from such emission streams: pre-combustion; post-combustion; and oxyfuel combustion.

Pre-combustion reacts a primary fuel with air or oxygen and steam to produce hydrogen and carbon monoxide which can be further treated to produce more hydrogen and CO_2 (15%-60% by volume), which can then be separated. The hydrogen (synthesis fuel) can be used for energy, with water as a by-product; the CO_2, at relatively high pressure and concentrations, is more amenable to capture than would have been the case if the fuel were combusted as is. This type of technology is used in Canada in four coal-fired integrated gasification combined cycle (IGCC) plants, although none capture the CO_2. The production of synthesis gas is relatively old technology but has been used in combination with pre-combustion capture only in specific circumstances.

Post-combustion processes generally use a recyclable solvent to trap CO_2 in the emission stream, though some projects are attempting to demonstrate biogenic capture through photosynthetic algae. Post-combustion capture has been used only in specific circumstances.

Oxyfuel combustion burns the primary fuel in almost pure oxygen to produce a very pure CO_2 stream which then can be compressed for storage purposes. This process, however, requires a fairly elaborate mechanism to purify the oxygen. Oxyfuel technology is in the demonstration phase. In other cases, such as fertilizer production (ammonia), CO_2 is separated as part of the chemical process of producing the product. These latter types of operations operate already in a mature market, though once again not in combination with storage.

Storage of CO_2 is mostly discussed in terms of geological storage, though oceanic storage has also been noted as a possibility. Geological storage can take place in oil and gas reserves, deep saline aquifers and unminable coal beds. The injection of CO_2 at pressure into these formations, generally at depths greater than 800m, means that the CO_2 remains a liquid and displaces liquids, such as oil or water, that are present in the pores of the rock.

Liquid CO_2 is lighter than water and therefore tends to travel upward; thus, suitable geological formations must have a "cap" rock to act as a barrier to its movement. If the cap rock is insufficiently wide, CO_2 could leak out around the edges. In this case, mechanisms would be required to prevent such leakage. The viability of any such project would have to be established on an individual basis.

There is also the possibility of injecting CO_2 into the deep ocean. CO_2, however, reacts with water to produce carbonic acid, which makes the water more acidic. Many aquatic organisms are highly sensitive to changes in acidity, making oceanic storage more problematic than geological storage from an ecological standpoint. Models assuming that oceans are used to contribute 10% of CO_2 emission reductions toward a stabilization of atmospheric CO_2 at 550 ppm (it is currently at 380 ppm;

Source: of above **Carbon, Capture and Storage: Technology, Capacity and Limitations**

Prepared by:
Tim Williams
Science and Technology Division
10 March 2006. prepared for Canadian Houses of Parliament.

Separation technologies

Solvent absorption; currently adopted in variety of uses but large demand for power

Membranes; applied on small scale only technical challenges on composition and temperature of flue gases

Adsorption: untried

Solvent absorption involves cyclical process in which CO_2 is absorbed from a gas stream directed into a liquid, typically an amine. The gas stream is emitted into the atmosphere. The CO_2 liquid is processed to remove the Co_2 which is then concentrated for storage.

Membranes made of polymers or ceramics sieve out CO_2 from gas streams. The membrane material is specifically designed to separate preferentially the molecules in the mixture. A range of configurations exist either simply as gas separation devices or incorporating liquid absorption stages.

Adsorption is based on based on a cyclical process in which CO_2 is adsorbed from a gas stream onto the surface of a solid. The gas stream is then emitted. The laden solid is purified in stages using differences in either pressure or temperature to remove and concentrate the CO_2 for storage.

Source: Peter J Cook, carbon dioxide capture and geological storage: research, development and application in Australia. International Journal of Environmental studies 63:6 731-749

Coal with and without CCS

- Estimates of incremental costs
- \$19-\$49 per tonne of CO_2. coal based*.
- Models tend to take form of CGE e.g GTAP and partial engineering bottom up**.
- CCS not profitable without global market for carbon emissions
- *(stern page 251. source IPCC)

Differences function of fuel type, carbon content Chemical costs, capital cost of capture and seperation plant process, operating costs, distribution and energy costs.

**(Paper by McFarland, Herzog and Reilly 2004 is a good example)

Most of China and US coal used for electricity generation is Bituminous coal which has a large range of carbon content some estimates say from 45-86% not clear where within this range Chinas coal fits in. And coal type; seperation costs highest with Lignite; lowest with Anthracite. Similar to mix in US where bituminous and subbituminous coal types predominate in current coal output. US has 7.3billion tonnes of Anthracite reserves. Source: American Coal Foundation.

Note increased costs estimates of CCS from IPCC significantly lower than earlier estimates. David and Herzog (2000) estimate incremental cost of applying CCS to new conventional coal stations would be around \$225/tc . Not clear whether IPCC include costs of energy needed to do capturing and storage. Herzog et al 2004 in a later paper estimated the costs of coal CCS at much lower \$90/tc.

David and Herzog (2000) The costs of carbon capture. Presented at the fifth International Conference on Green House Gas Control technologies, Cairns, Australia. (on google scholar)

J R Mcfarland, H J Herzog, and J Reilly. Representing energy technologies in top-down economic models using bottom-up information Energy Economics volume 26 Issue 4 , July 2004, pages 685-707.

China fuel cost per Kwhr

Coal 17 yuan

Gas 30 yuan

He Youguo

China Coal Industry Development Research

and Consulting Co. Ltd. Believable ?

Why China?

China

- Highest emitter of CO_2
- 70% of electricity generation from coal
- Relatively low alternative reserves of oil and gas
- Seen as strong candidate for CCS

Latest UN figures are for 2004. they show US as largest emitter at 6 billion metric tonnes (6,049,435 thousand metric tonnes) China and Taiwan at 5 billion metric tonnes. Preliminary 2006 estimates by among others the Netherlands Environment Agency put China ahead of the US.

Energy intensity is Chinas economy declining but rapid growth means total emissions still expected to increase at around [3%] according to Stern.

China energy production in 2006 (latest data available) coal 76.7 % of production; oil 11.9% , hydro 7.9% gas 3.5% . Source National Bureau of Statistics of China.

China is seeking to diversify by securing alternative sources of energy through imported gas or domestically through wind power and solar panels

Application to China

- Why bother
- Problems of wait and see
- Adoption: lead or follow innovation.
- Cost pass through: impact on home and foreign

Why bother, self interest. costs of climate change through more drought, reduced water supplies in west (longer term less annual snow melt as glaciers disappear) flooding in south, heat waves on east coast. Benefits temperate zone moves north. Greater crop yields. Health. Like Nox ,and Sox ,CO_2 causes significant breathing problems for significant portion of population. Economic loss from flooding 1.2% GDP and drought 0.8% China 1988-2004 according to Stern Page 122

Adoption and diffusion of CCS

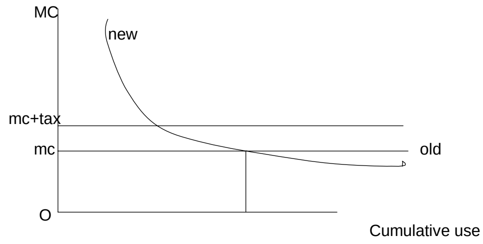
General issue is wait and see

General approach is S shaped adoption curve. (Early adopters, take off through diffusion, maturity. (through time)

Check slide. Add example of approach based on modelling . Much reduced form of general approach to analysing adoption and diffusion of novel technologies. Insert example from Sue Wing and Popp.

Wait and see

Marginal costs of production (new and old technologies)



Learning rates for energy technologies%

Learning rates for energy technologies(%)

Technology	Europe	US	R of W
Photovoltaics	35	18	
Wind	18	32	
Biomass	15		
Ethanol			20
Coal	4		

Not helpful

Role of early adopters

- Prepared to take on costly experimentation
- Expect to be rewarded with significantly higher profits at later date.
- Cost and benefits of being first
- Traditionally look for niche markets, and offer novel superior product.
- Emphasis on Learning by doing

Firm experimentation tends to focus on minimising costs of technological, market and financial risk.

Treat market for CCS technology as requiring initial relatively high levels of fixed capital investment; in say carbon separation plant, compressors and pumps, pipelines, drilling wells for storage, and capping wells to prevent leakage. Cost profile is one of high fixed sunk cost; low long run marginal cost.

Source of clear benefits of being first. Precommitment to enter deters others contemplating market entry subsequently. Requires significant scale economies. First in the market expands output rapidly and with this benefits from falling marginal unit costs. Followers' or subsequent entrants face the choice selling little output at small volumes at higher than incumbent costs or trying to match incumbent costs by expanding output. Expanding output increases industry supply and in markets with a few firms this will lower industry price.

But presupposes first mover has distinctive competence or firm specific expertise; knows with high levels of certainty the size of the future market, the size of the fixed costs needed achieve minimum efficient scale and hence the shape of a downward sloping average and marginal cost curve. It also supposes firm has a reliable and accurate basis for knowing what configuration of factor inputs, (labour, technology, knowledge, processes and functions) and their price are required to supply this market at desired levels and costs.

Where these conditions do not hold the advantages of being first require, generally that there is a very high probability that the full costs of experimentation to reduce uncertainty are less than the possible profits from market entry. They also require that the benefits of learning by experimentation are kept private. New and beneficial knowledge does not leak out into the market.

The benefits of being second stem from knowledge spillovers incurred by the firm that was first at significant cost but the second mover at significantly less cost.

Knowledge accumulation and LBD complements and not substitutes

Or is learning by searching more efficient

Role of Diffusion

- Knowledge transmission/knowledge receipt
- Benefits received
- Costs of adoption
- Relevance of industry sector

Standard economic theory postulates slow rate of adoption , over time then acceleration

Absorption costs of adopting new technology: cost of acquisition plus [larger] costs of complementary investment , costs of learning all required to make use of technology.

CCS costs of experimentation

- Start with around £1bn
- Small elephant or large mouse.
- Market risk far greater than technology risk
- Should China free ride on others or go first?

£1bn may seem large. But it is around one twenth of the cost of building a seven barrage. One 5000th of the assets held by banks in the UK, a very small fraction of US or China GDP. Expectations of market for new CCS technology heavily reliant on governments creating market for clean low carbon technology.

Governments as creators of markets

- Regulation and environmental innovation
- Market instruments as creator of market for low carbon technology
- Huge intergovernmental challenge but lets be optimistic

CCS only likely to work if there are significant costs of emitting CO_2 from coal fired and other kinds of power stations and process plant installations. Otherwise installations with CCS would be at a cost disadvantage compared to carbon emitting generation plant. So attraction of large monopoly profits may not hold. Some firm specific attribute that encourages belief of superior competitiveness

Lead or Free ride

Essentially about:

- Incentives to innovate and costs of experimentation
- relative position of firms in China to current technology frontiers
- Absorption costs of new
- Intellectual crowding out

General presumption that CCS in China will have to be based on technology transfer either through imports or FDI. Worth reviewing whether true. According to Keller W (J of Econ lit 2004) There is no indication that international diffusion is inevitable or automatic, but rather, domestic technology investments are necessary.

Incentives and costs of experimentation; see earlier slide.

The issue on technology frontiers is whether Chinese firms have both the same level of knowledge of the technologies needed for CCS and can apply that knowledge in an equally efficient way as the most efficient firms in the rest of the world. There is an increasing body of evidence to suggest firms at the frontier are likely to be efficient at moving beyond it than firms well inside the frontier (ie. Less able to generate and exploit novel technologies) . And where the new technology has sufficient similarities to current technology in terms of required understanding and factors needed to exploit it. Which is why might expect CCS to be based on consortium of firms each with specialist expertise in capture, transport and store. This raises a set of other issues around integration, coordination and sharing costs and benefits. But for another time.

But issue not a single frontier. Rather it is combination of technologies at numerous technology frontiers and the efficiency of integration of these complementary technologies. Question also the requirement of complementary factors.

Knowledge accumulation usually proxied by firm investment in R and D, number of patents applied for.

OECD comments on China innovation system. "Excelled in mobilising resources for Science and Technology and now "major R and D player" But expenditure has not translated into innovation performance. One reason for this is because capabilities for making productive use of accumulated investment in R and D …. Have developed at a much slower pace. Source: OECD reviews of Innovation Policy CHINA. Synthesis report. 2007.

Literature on incentives. Scope for monopoly profits; economic rents. Impact of regulation on incentives. Under investment because of externalities; wedge between private and social return. Question is open innovation more relevant than closed. Strength of IP protection. Is it needed. Relevance of speed of Technological change.

Cost pass through

Crude pointers

- Market shares (%): Industry 75, households 11, (electricity consumption)
- Market structure and competition
- Own price elasticity
- Export competitiveness
- More spending; less saving

Assume monopoly with no significant trade. Although some substitutes possible. e.g. own generator. Consumption of other fuels for heat.

Assume also relatively inelastic own price. So high pass through. Figures from National Bureau of statistics in China.

Industry . Household penetration. Proximate measure urban households with an electric oven. 98% but rural much less about 50%. Do not know how much is due to households with small generators. Assume positive network externalities of electric grid much larger in cities than rural areas. Rising cost of supply curve of increased rural coverage.

Energy intensity and export specialisation

Major sector users	Electricity intensity	Export share %
Chemicals	0.45	4.6
Iron and steel	0.43	3.4
Aluminium	0.57	1.8
Textiles and clothing	0.06	14.9
Non metallic minerals	0.45	0.003
Electric power and heat generation	0.60	n.a
Office and telecom equip.	0.06	30.6

Electricity intensity defined as kwhr electricity consumed per unit of sector value added measured in yuan source: national Bureau of Statistics of China and WTO

Tentative observations

- Some CCS technically feasible technologies
- Gap between technical feasibility and point of commercial viability seems to be narrowing.
- Standard refrain on CCS is there is a coordination and sequencing problem.
- Could a Chinese/US technology JV be the joint first movers?

Firms will not commit to full scale demonstrators until they are clear that there will be a market for CCS technology. Market either has to come from marked shift in consumer preferences for low carbon electricity generation and reflected in willingness to pay. Alternatively governments must impose implement and enforce system for polluter pays; preferable through a probably function market for permits.