EARLY BARRIERS TO BE REMOVED
FOR DEPLOYMENT OF LARGE SCALE CO₂ CAPTURE AND
STORAGE SYSTEMS IN EUROPE AND IN FOREIGN
COUNTRIES  *

Angelo Spena

Head of Doctorate on Energy Sources Engineering - Department of Ingegneria dell’Impresa
University of Roma Tor Vergata - Via del Politecnico, 1 – 00133 Rome - Italy

e-mail : spena@uniroma2.it

ABSTRACT

An attempt to identify the barriers to be removed in order to kick-start an efficient transfer of material and immaterial tools for CCS practice is mased. Early management problems appear to be technology assessment for retrofitting existing plants, safety and risk analysis of CO₂ transportation and storages, planning for regulation and standards to improve the CO₂ value chain, modelling and improving a future CO₂ grid system. To do this, the assessment of the experience on the management and regulatory framework of the existing grid systems as a starting point is stressed. A nomogram is also proposed to compound energy and environmental future costs and benefits.

1. INTRODUCTION

According to the recent EU Commission Set-Plan - Final Document COM (2007) 723 of 22.11.2007, where “focus on the whole system requirements, including efficiency, safety and public acceptance to prove the viability of zero-emission fossil fuel power plants at industrial scale” is recommended [1], in the present paper a comprehensive review of the main barriers to kick-start an efficient transfer of both material and immaterial tools for CCS practice, between EU and foreign Countries, especially China, is attempted.

We will deal with, assuming the following statements as starting points.

Even if in smallest scale systems, CO₂ has been handled successfully for decades so that risks implied with its use have been effectively managed or mitigated. Also the transportation of CO₂ is already well understood – while it has been shipped regionally in small liquid quantities for the last 20 years, and a more than 2500 km onshore network has been in operation in the USA for the past 30 years.

Development of first-generation CCS technologies could usefully adopt methods and tools from related areas, mainly from oil and gas production. As a matter of fact CO₂ capture plants and transports already have well-established directives and national legal frameworks; whilst storage facilities can adapt current mining and petroleum laws, whereby the governmental administration assumes liability after a law-regulated abandonment process.

Sources with high CO₂ concentration are most attractive because capture can be implemented at lower costs [2]: so its large scale factor makes power generation the main field of CCS applications. The use of CO₂ in industrial processes and products (urea fertilizer production, greenhouses for agriculture etc) also could be considered, but only in the short-term, due to the fact that it is smaller and not yet included in the ETS system.

2. MACROECONOMIC SCENARIOS

CCS is a “bridge” technology. But a fully carbon free technology fit to replace fossil fuels (nuclear included) is far from any foresight. Governments could utilise CCS not only to meet emission targets, but to offset costs by using the CO₂ to increase oil production. Their involvement could also reduce risks at all levels of the CO₂ value chain by promoting it in its developmental phases, by supporting the implementation of new capture technologies and by facilitating contracts between consenting companies. An inverse

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correlation between the relevance of environmental taxes and emission patterns for the overall economy (see Fig.1) is widely recognized [3], so that macroeconomic links and constraints need to be considered and evaluated. Also highly dedicated modelling tools need to be developed, aimed to afford accurate sensitivity studies so that optimal infrastructure lay-outs could be defined.

Fig. 1 - Environmental related taxes and CO₂ emissions: the case of Italy.

To do these several activities are needed, referred to both time and industrial enhancement output forecasts in a ten-years time scale:

2.1 Forecast of a set of scenarios in terms of trends of energy demand and of technologies for energy generation and supply
2.2 Outlook of the impact of changes of energy commodities scenarios on foreign policy and global energy markets governance
2.3 Characterization of the sites (power stations and mines-reservoirs) and of the relating pipelines by means of algorithms suitable for simulation
2.4 Characterization of the impacts of power stations and pipelines by means of algorithms
2.5 Forecast of the availability of mines-reservoirs vs energy consumption growth
2.6 Evaluation of costs of the previous items, for several growth scenarios
2.7 Validation of data base files, of algorithms and models with case studies, submission of the results to sensitivity analysis to ascertain crucial departures of main parameters
2.8 Assessment and forecast of technological outputs of the industry of combustion devices, of gas reactors, of gas and slurry piping compression and operation, and of the great underground construction

2.9 Forecast of new topics on logistics, safety and reliability of large power systems, on communications, on environmental satellite monitoring.

3. ASSESSMENT OF THE AVAILABLE TECHNOLOGIES AND RETROFIT

Although not fully carbon free (about 90% capture rate) CCS could provide a first attempt in decoupling of fossil fuel use from emissions. As a matter of concern, two decades more without commitments would make also reasonably goals not only extremely expensive, but probably unachievable [4]. Given the urgency of the situation, deployment of CCS must begin with the implementation of the most promising technologies available today. The oil and gas industry already run large chemical plants similar, although in scale, to some types of CO₂ capture facilities fit for power generation.

As far as power stations are concerned, in addition to the yet ready-for-use post-combustion techniques, other options (see Fig.2) could be attractive in the short term, like in the case of pre-combustion with other raw sources, such as hydrogen, biomass, SNG, methanol, diesel fuel and naptha [5].

Fig. 2 – Suitable technologies assessment [5].

Thus the following activities should be planned:

3.1 Survey and selection of the most suitable technologies for the different kinds of power stations, either in China and in Italy in this case-study
3.2 Assessment of the life-cycle of each existing power station which need to be in any case replaced or repowered by the year 2015, in order to implement them mainly with ready-to-use CO₂ capture techniques
3.3 Assessment of the investments and of the time required to implement the selected technique in the retrofit mode

3.4 Survey of the available infrastructures (pipelines, ships, highways, railroads etc) and components (compressors, offshore platforms, wellheads, control systems etc), originally designed to transport and handle natural gas or petroleum products, which can be retrofitted for CO₂ transport

3.5 Survey of the existing SMEs fit to operate and grow in the fields involved by CCS, at any industrial and commercial level

3.6 Study of mechanisms of sustainment or of fiscal incentives for the take-off of SMEs in the main plants sector as well as in the induced manufacturing sectors

3.7 To identify niche markets where costs and incomes are acceptable for either CO₂ trade and end-use as commodity or by-product.

In order to process the above data in a global scenario and to give first approach results about reciprocal links and related effects, in Fig.5 an original nomogram is proposed. The following quantities are considered: costs of power installation and of energy generation (see Fig.4 for more detail), costs of CO₂ removal (when considering mean feature levels of capture, transport and storage processes), power generation and CO₂ removal efficiencies, ETS evaluation reference levels. Social costs are also taken into account. In present paper the case study of Italy and China is stressed [6] with respect to two scenarios: of the year 2005 and of the year 2030. As a matter result, CCS technologies appear more beneficial in the developing country considered, while the departures between the China and Italy appear decreasing with the time, but only in absolute value. Fig.5 shows that presently the cost of CO₂ removal is in Italy of about 0.05 $/kWh, while in China it reaches 0.08 $/kWh. In the year 2030 these costs will be of 0.025 and of 0.04 $/kWh respectively. As a consequence, the present increases of the energy cost in case of CCS technologies implementation (in Italy of about 140% while in China of 800% and more), will drop in the year 2030 to 70% and 400% respectively.

Fig. 4 – Adopted costs of power availability $C'_i$ (per year), and of energy generation $c$, vs. exploitation time.

**4. SELECTION CRITERIA FOR GEOLOGIC SITES**

Much of the technology needed for monitoring the geological storage of CO₂ can be adapted from hydrocarbon exploration and development activities, at least at a first approach [7].

From this point of view, depleted oil and gas fields appear attractive: not only thanks to the geology well understood and the to their potential for recycling of the existing infrastructures, but also for the intrinsic opportunity to offset costs from the additional oil production. Enhanced Oil Recovery (EOR) may also be combined with the storage of even more CO₂ after the commercial lifetime of the fields end. (And the infrastructure would be in the future upgraded to provide hydrogen [8] as a transport fuel). Other promising options at the experimental stage are Enhanced Gas Recovery (EGR), Enhanced Coal Bed Methane and, although limited, Deep Unmineable Coal Beds, which may become quite important in some “coal provinces” (is this the case of China).
In this field, the following activities are necessary:

4.1 Field studies to investigate opportunities for using CO$_2$ in EOR
4.2 Survey of the existing data referring to geological sites of interest for CO$_2$ storage
4.3 Survey of the existing techniques for selection and validation of sites in similar systems (gas and oil reservoirs, nuclear wastes, earthquakes risk and safety problems etc)
4.4 Comparison between the different needs and requirements and studies (outlooks) to draw guidelines for future research.

5. SAFETY ASSESSMENT OF TRANSPORT AND STORAGE

As outlined earlier, much of the experience in hydrocarbon pipeline could be directly transferred to the CO$_2$ transport. There is also extensive knowledge of the Liquid Propane Gas and of the Liquefied Natural Gas industries upon which we can draw [9].

Operation and maintenance of transport and storage facilities could be managed by Companies subject to a regulated revenue scheme, similar to those for natural gas and electricity transmission activities. Thus, transparent and non-discriminatory rules and tariffs for third party
access to the CO₂ infrastructure will also need to be established.

To avoid the danger that oil and gas fields will be closed down without realising enough potential of CO₂ for EOR (or EGR, other chance), also unmineable coal beds or closing coal mines, especially in China, should be surveyed and maintained in a stand-by state.

The major reason of fears appears CO₂ leakages [9]. Although any CO₂ leakages could be identified and timely avoided thanks to reliable risk monitoring systems, clear regulations on liability must be established, based on the principles of the EU Environmental Liability Directive. Also purity of CO₂ will be a critical issue. There is a trade-off between the purity of CO₂ the process produces, and the cost of the technology required. What constitutes reasonable levels of quality will be agreed between producers, transporters, pipeline owners and storage owners. Also standards for CO₂ (emission, leakages, handling, safety etc) and other new constituents will be required, starting from adapting actual standards available for other substances. Indeed, the CCS liability issues are actually very similar to those of other industrial activities and gases.

In this framework, the following activities should be planned:

5.1 Assessment of the effectiveness of experienced leakages and of potential for causes
5.2 Monitoring prior to implementation and measurements of background levels of CO₂ emission, comprising seasonal variations and departures, over a comprehensive period of time
5.3 Survey of the available techniques for control, monitoring and remediation in similar systems (oil, gas and refinery industries, pipelines and hydrocarbons fields)
5.4 Comparison between the different needs and requirements and outlooks aimed to give guidelines for future research
5.5 Development of tools fit for testing innovative processes or storage facilities, including pilot plants for CO₂ capture and leakage laboratories.

6. MODELS FOR A FUTURE CO₂ GRID SYSTEM

In a fully developed CCS system, it will be industries handling transport, and maybe systems of underground reservoirs where the producers can buy storing services for their CO₂. This will reproduce on the CO₂ pipeline grid several well known problems of the electrical or hydrocarbons grids (like dispatching, logistic, locational signals, operational problems etc). Studies are then required to determine the best infrastructure routing, while minimizing internal and external (environmental and social) costs.

To do this, a set of activities appear to be needed:

7.1 Survey of the state-of-the-art techniques for modelling, planning and optimize the technical features of grids in similar systems (gas, oil, electricity)
7.2 Survey of the limits and affordability of state-of-the-art techniques for modelling dispersion, diffusion, flue gases (as CFD)
7.3 Survey of the state-of-the-art techniques for modelling, planning and optimize governance aspects of grids in similar systems (gas, oil, electricity)
7.4 To validate any differences between transportation of hydrocarbons, both inshore and offshore, and that of CO₂
7.5 To identify the most cost-effective solutions for linking sources to storage location, each taking into account its own local constraints and public concerns
7.6 Forecasts for a global decommissioning time-plan of the existing reservoirs and mines.

7. REGULATORY ACTIONS TO IMPROVE CO₂ VALUE CHAIN

Many international, regional and EU legal frameworks are already relevant to CCS, with definitions and prohibitions that are sufficiently broad to encompass and regulate various CCS activities. However, only a few explicitly address them. Laws and treaties regulating the economics involved when CO₂ crosses country borders are needed, consistent within all the countries potentially involved in a CO₂ infrastructure. This also implies to compound policies for planning investments in either oriented economy and in market economy (or hybrid, like China): as a matter of certainty, investors convinced that CCS technology has a robust, long-term perspective, with the right incentives can deliver solutions. Otherwise, delay would be costly and dangerous. It means establishing a clear, stable fiscal and regulatory framework, to create a level playing field for all industrial actors within a common legislative framework as broad as possible while avoiding over-regulation. Indeed, the larger the
system, possibly worldwide, the more stable it will be. This framework should also have a long lifetime – of the order of 30 years.

Consistent regulation at both national and international levels could also ensure harmonisation of the process chain and compliance with health, safety and environmental requirements. A clear risk management strategy need to be developed, including Risk Acceptance Criteria, in order to drive regulations, ensure compliance by producers, transporters and storage sites operators; and, crucially, gain public acceptance. In this framework, all methodologies should be considered, with Features-Events-Processes and the Decision&Risk Analysis the front runners as they employ a very direct approach.

It must be remembered that the affordability of the project of an overall continental grid (in Europe, as well as in China) depends on the total supply and demand of manufacturing infrastructures available on the worldwide market. The starting point for this development is therefore the identification and the transfer of technology, know-how, and experience from all the parts of the world.

We must also implement the Emission Trading Scheme based on the Kyoto Flexible Mechanisms, especially with regard to the CDM allowing the industrialized countries with a GHG reduction commitment, to invest in emission-reducing projects in China, India or similar countries as an alternative to higher costly reduction projects within their own countries. Avoidance of emissions to the atmosphere through CO$_2$ capture and long-term geological storage could be treated as equivalent to emission reduction at the source. It should therefore receive similar incentive treatment as renewable energy sources and energy efficiency programmes. It is also essential that CO$_2$ used for CCS projects is fully accredited under EU ETS, as well as the CDM.

As a matter of interest, in Figs. 6 and 7 respectively are reported rough estimations of the benefits of CCS implementation, when considering the amounts of CO$_2$ emitted in atmosphere, in Italy and in China. For both the countries, are separately considered the case of retrofitting the existing plants and the case in which only new power stations will be implemented with CCS. The slope of the curves is proportional to the mean efficiencies of power generation. With attention paid to the different abscissa scales, an outlook to the 2030 year clearly shows that retrofit, surely most beneficial in Italy (and in Europe in general), should be carefully compounded, in rapidly growing countries like China, with interventions made on future installations. This qualify for the great importance of any long-term scenario.

![Fig. 6 - CO$_2$ emissions vs. power implemented with CCS in retrofit mode (left side) or in new power stations (right side). The case of Italy.](image)

![Fig. 7 - CO$_2$ emissions vs. power implemented with CCS in retrofit mode (left side) or in new power stations (right side). The case of China.](image)

Most analyses of the Kyoto flexible mechanisms show that mitigation costs are lower in a global permit market than in regional markets or in permit markets confined to Annex I countries. The benefits of allowing traders to bank their permits for future use should be quantified as possible. Recent studies [11] suggest that banking could not only increase economic efficiency, but also the environmental effectiveness of climate policy, especially in the short term (see Fig.8). Indeed, any increase on the amount of emissions abated in the next first decade, will reduce the risk of irreversible environmental impacts as threatened by the claimed climate changes.

Last, but not least, the use of insurance or related financial mechanisms should also be explored, including the possibility for specific Funds – financed by storage sites operators – to
cover liability of the storage site, both during operation and after its transfer to the governmental administrations.

![Graph](image)

**Fig. 8** – Carbon prices forecast for different allocations schemes: Contraction and Convergence CC, Sovereignty SOV, equal Emission Per Capita EPC.

On the basis of what above, to assess the CO₂ value chain and to identify the barriers for integrating CCS cooperation, the following activities should then be planned:

7.1 Survey of the available tools: studies of the analogies between the CCS system and the regulatory framework of all similar existing systems (electricity, oil, gas)

7.2 To amend present EU and China legislation, especially concerning waste and water, in order to clarify the conditions under which CO₂ can be stored underground and to allow geological storage experiments

7.3 To amend and to implement the existing requirements (standards, features etc) about material and components to be used for CO₂ pipelines and plants, and to clarify the conditions under which geological storage of CO₂ qualifies for EU Emission

7.4 To establish transparent, non discriminatory rules and tariffs for third party access to the CO₂ infrastructure

7.5 To define international standards for leak detection, for purity of CO₂, for background levels estimation, for risk analysis

7.6 To make a worldwide recognition of all international treaties, in order to coordinate them for benefiting from economies of market-scale

7.7 To implement Trading Scheme ETS and other incentive mechanisms and to establish long-term sustainable mechanisms to supplements EU ETS

7.8 To simulate the efficiency and distributional consequences of allowing markets in order to optimize the allocation of emission permits either across regions, either over time

7.9 To explore insurance or related financial mechanisms, as specific Funds, and to improve strategies and international partnership activities.

### 8. COMMUNICATION AND KNOWLEDGE DISSEMINATION

To reassure the public and convince them of the necessity of deploying CCS as soon as possible within the framework of new laws, treaties and regulations, timing is critical: while in some countries CCS is moving onto the policy agenda relatively quickly, in others there is still virtually no recognition of CCS, even in policy circles.

To avoid secretive approach with only reliance on the opinion of experts, with the consequence of people distrust, it appears crucial to maintain an open dialogue with the public - especially if having storages in their neighbourhoods - on all aspects of the CCS technologies, in equal and balanced terms within all the countries potentially involved, either in the EU as in relating extra EU countries. On the other hand, to make next generation technology ready for implementation by 2020, longer-term exploratory research into advanced, innovative concepts must start immediately. It means to provide dedicated training and education to firms - especially SMEs - and to the next generation of professionals.

For this strategy the following activities appear essential:

8.1 To implement education, in order to achieve a global approach to the problem from an interdisciplinar point of view involving engineering, geo-sciences, biology, financial, legal, communication and social sciences.

8.2 To involve doctorates and other advanced training scools when organizing meetings, conferences and seminars

8.3 To promote knowledge transfer between European research centers, and to support the establishment of network in key technologies.

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