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To Whom it may concern
SET-PLAN-SECRETARIAT
European Commission

Stakeholders Opinion
Lodz University of Technology, Poland

As the researchers of Lodz University of Technology in Poland, we agree with the targets set in the issue paper. We strongly recommend the realization of the key technology-related objectives for CCS, both in the short and longer term, to deliver the commercial-scale demonstration of the full CCS chain, and to reduce the costs of CO_2 capture through Research and Innovation. In our opinion the level of ambition is correct nevertheless requires urgent decisions (during the summit on the 24th May 2016) to carry them into effect as soon as it is possible (this year). As the Polish researchers we also recommend the standing of the Polish Steering Committee SET-Plan concerning the CCT.

Refer to SET PLAN ACTIONS, especially to **Additional priority 1: Driving ambition in carbon capture storage and use deployment (Action 9)**, the following positions can be expressed. Due to state of art in the field of CCS technology, all UE members countries (especially Poland) should intensify process of commercial deployment and jump from lab into full scale process.
Accoring to the SET Plan Issue in the short term – by 2020, we recommend focusing on the achievement of the following objectives:

- At least 3 pilots on promising new capture technologies, and at least one to test the potential of Bio-CCS;
- At least 3 new CO_2 storage pilots3 in preparation or operating in different settings;
- Completed feasibility studies for the use of captured CO_2 for fuels and value added chemicals;
- At least 4 pilots on promising new technologies for the production of value added chemicals from captured CO_2.

The achievements of the presented objectives above as the main target and priorities in the first stage guarantee to gain the knowledge and advanced technologies to continue the implementation work in the second stage, which is expected to realize by 2050.

There are some key areas that might convert from laboratory and bench scales at the early stage of process development into successfully constructed and operated in a controlled environment. The conceptual design stage of a CO_2 capture process is one for which the basic science has been developed, but no physical prototypes yet exist.

Post-Combustion Capture

1. The most advanced systems today employ amine-based solvents, while processes at the earliest stages of development employ a variety of novel solvents, solid sorbents, and membranes for CO_2 capture or separation. The amine systems can be installed at power plants (burning coal). The CO_2 captured at these power plants might be sold i.e. to food processing facilities, which use it to make dry ice or carbonated beverages. The oldest and largest commercial CO_2 capture system operating on such a way is the IMC Global soda ash plant in California. Here, the mineral trona is mined locally and combined with CO_2 to produce sodium carbonate (soda ash), a widely used industrial chemical. All these products soon release the CO_2 to the atmosphere (e.g., through carbonated beverages).
   As a good location can be shown power plants in Polish cities, possess power plants to produce heat or chemical plants treat with soda.

2. Amine-Based Capture Processes use solvents called amines (more properly, alkanolamines) are a family of organic compounds that are derivatives of alkanols (commonly called the alcohols group) that contain an "amino" (NH_2) group in their chemical structures. These processes are limited by the energy cost required for solvent regeneration, which has a major impact on process costs.
   To use A-B CP in full industrial scale some financial mechanism can by apply to lower the overall cost of installation maintenance.

3. Ammonia-Based Capture Processes seems to be very promising to due to the overall cost of an ammonia-based system would be substantially less than an amine-based system for CO_2 capture. Since ammonia potentially could capture multiple pollutants simultaneously (including CO_2, SO_2, NO_x), the overall plant cost could be reduced even further. Ammonia-based systems are attractive in part because ammonia is inexpensive, but also because an ammonia-based process potentially could operate with a fraction of the energy penalty of amines.

The CCS technology use in lab scale has been summarized in Table 1

Table 1. Post-Combustion Capture Approaches Being Developed at the Laboratory or Bench Scale

Liquid Solvents	**Solid Adsorbents**	**Membranes**
Advanced amines	Supported amines	Polymeric
Potassium carbonate	Carbon-based	Amine-doped
Advanced mixtures	Sodium carbonate	Integrated with absorption
Ionic liquids	Crystalline materials	Biomimetic-based

Source: Edward S. Rubin, Aaron Marks, Hari Mantripragada, Peter Versteeg, and John Kitchin, Carnegie Mellon, University, Department of Engineering and Public Policy.

4. Liquid Solvents (typically a mixture of a base and water) selectively absorb CO_2 through direct contact between the chemical solvent and the flue gas stream. In general, the aim of solvent research is to identify or create new solvents or solvent mixtures that have more desirable characteristics than currently available solvents. Such properties include increases in CO_2 capture capacity, reaction rates, thermal stability, and oxidative stability, along with decreases in regeneration energy, viscosity, volatility, and chemical reactivity. The main advantages and challenges associated with liquid solvent-based approaches to post-combustion CO_2 capture have been presented in table 2.

Table 2. Technical Advantages and Challenges for Post-Combustion Solvents

Description	Advantages	Challenges
Solvent reacts reversibly with CO_2, often forming a salt. The solvent is regenerated by heating (temperature swing), which reverses the absorption reaction (normally exothermic). Solvent is often alkaline.	Chemical solvents provide fast kinetics to allow capture from streams with low CO_2 partial pressure. Wet scrubbing allows good heat integration and ease of heat management (useful for exothermic absorption reactions).	The large amount of steam required for solvent regeneration de-rates the power plant significantly. Energy required to heat, cool, and pump non-reactive carrier liquid (usually water) is often significant. Vacuum stripping can reduce regeneration steam requirements but is expensive; bad economy of scale. Multiple stages and recycle stream may be required.

Source: U.S. Department of Energy, *DOE/NETL Carbon Dioxide Capture R&D Annual Technology Update*, Draft, National Energy Technology Laboratory, Pittsburgh, PA, April 2010; hereafter "DOE, Carbon Dioxide Capture."

Examples of promising solvents include new amine formulations, carbonates, certain blends of amines and carbonates, and ionic liquids. For example, a promising new amines now receiving attention is piperazine. This solvent, currently being studied at the University of Texas and elsewhere, has been shown to have faster kinetics, lower thermal degradation and lower regeneration energy requirements than MEA in experiments thus far.30 Further characterization studies are in progress.

Potassium carbonate solvents, which have been used successfully in other gas purification applications, absorbs CO_2 through a relatively low-energy reaction, but the process is slow. Researchers are attempting to speed up absorption by blending potassium carbonate with various amines, with promising results. *("Carbon Dioxide Capture"; J. T. Cullinane and G. T. Rochelle, "Carbon Dioxide Absorption with Aqueous Potassium Carbonate Promoted by Piperazine," Chemical Engineering Science, vol. 59 (2004), pp. 3619-3630).*

5. Solid Sorbent Absorbtion (SSA)

Solid sorbents can absorb CO_2 on their surfaces. They then release the CO_2 through a subsequent temperature or pressure change, thus regenerating the original sorbent. Solid sorbents have the potential for significant energy savings over liquid solvents, in part because they avoid the need for the large quantities of water that must be repeatedly heated and cooled to regenerate the solvent solution. **Sorbent materials** also have lower heat capacity than solvents and thus **require less regeneration energy to change their temperature**.

The key aim of solid sorbent research is to reduce the cost of CO_2 capture by designing durable sorbents with efficient materials handling schemes, increased CO_2 carrying capacity, lower regeneration energy requirements, faster reaction rates and minimum pressure drops. Main potential areas promising to get some optimistic results by using such a way to post-combustion CCS are presented in table 3.

Table 3. Technical Advantages and Challenges for SSA to Post-Combustion CO_2 Capture

Description	Advantages	Challenges
Sorbent pellets are contacted with flue gas, CO_2 is absorbed onto chemically reactive sites on the pellet. Pellets are then regenerated by a temperature swing, which reverses the absorption reaction.	Chemical sites provide large capacities and fast kinetics, enabling capture from streams with low CO_2 partial pressure. Higher capacities on a per mass or volume basis than similar wet scrubbing chemicals. Lower heating requirements than wet-scrubbing in many cases (CO_2 and heat capacity dependent).	Heat required to reverse chemical reaction (although generally less than for wet-scrubbing). Heat management in solid systems is difficult. This can limit capacity and/or create operational issues for exothermic absorption reactions. Pressure drop can be large in flue gas applications. Sorbent attrition may be high.

Source: DOE, "Carbon Dioxide Capture."

6. Membrane-Based Approaches (MBA)

The main and key challenges to use MBA in commercial scale include the need for large surface areas to process power plant flue gases, limited temperature ranges for operation, low tolerance to flue gas impurities (or requirements for additional equipment to remove those impurities) and high parasitic energy requirements to create a pressure differential across the membrane (Table 4).

Table 4. Technical Advantages and Challenges for MBA to Post-Combustion CO_2 Capture

Description	Advantages	Challenges
Uses permeable or semi-permeable materials that allow for the selective transport and separation of CO_2 from flue gas.	No steam load. No chemicals needed.	Membranes tend to be more suitable for high-pressure processes such as IGCC. Tradeoff between recovery rate and product purity (difficulty to meet both at same time). Requires high selectivity (due to CO_2 concentration and low pressure ratio). Good pre-treatment. Poor economies of scale. Multiple stages and recycle streams may be required.

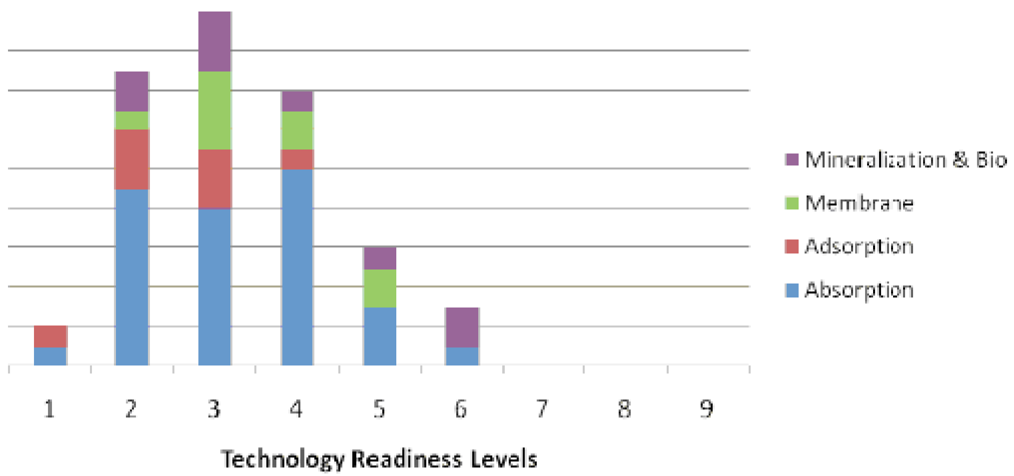
Source: DOE, "Carbon Dioxide Capture."

The researchers are investigating the development of ultra-high surface area porous materials for CO_2 capture. These materials are known as metal organic frameworks (MOFs, discussed earlier), zeolytic imidizolate frameworks, and porous organic polymers. These materials have pore sizes, surface areas, and chemistries that are highly "tunable," meaning that molecules can, in principle, be designed and fabricated by chemists and materials scientists to maximize CO_2 capture performance. Because CO_2 capture research in this area is relatively new, very little work has yet been done to assess these materials under realistic capture conditions or to incorporate them into workable capture technologies.

To summarize our opinion and the proposal for the development of the described processes concerning the Combustion Capture Technologies using different approaches we present the chart 1 showing the Technical Readiness Level (TRLs). The key questions that remain are:

1. What are the prospects for any of these projects to result in a viable new process for CO_2 capture?
2. How much improvement in performance or reduction in cost can be expected relative to current or near-term options?
3. How long will it take to see these improvements?

Chart 1. TRLs of Developing Post-Combustion Capture Technologies



Source: Bhown and Freeman, "Assessment Post-Combustion."