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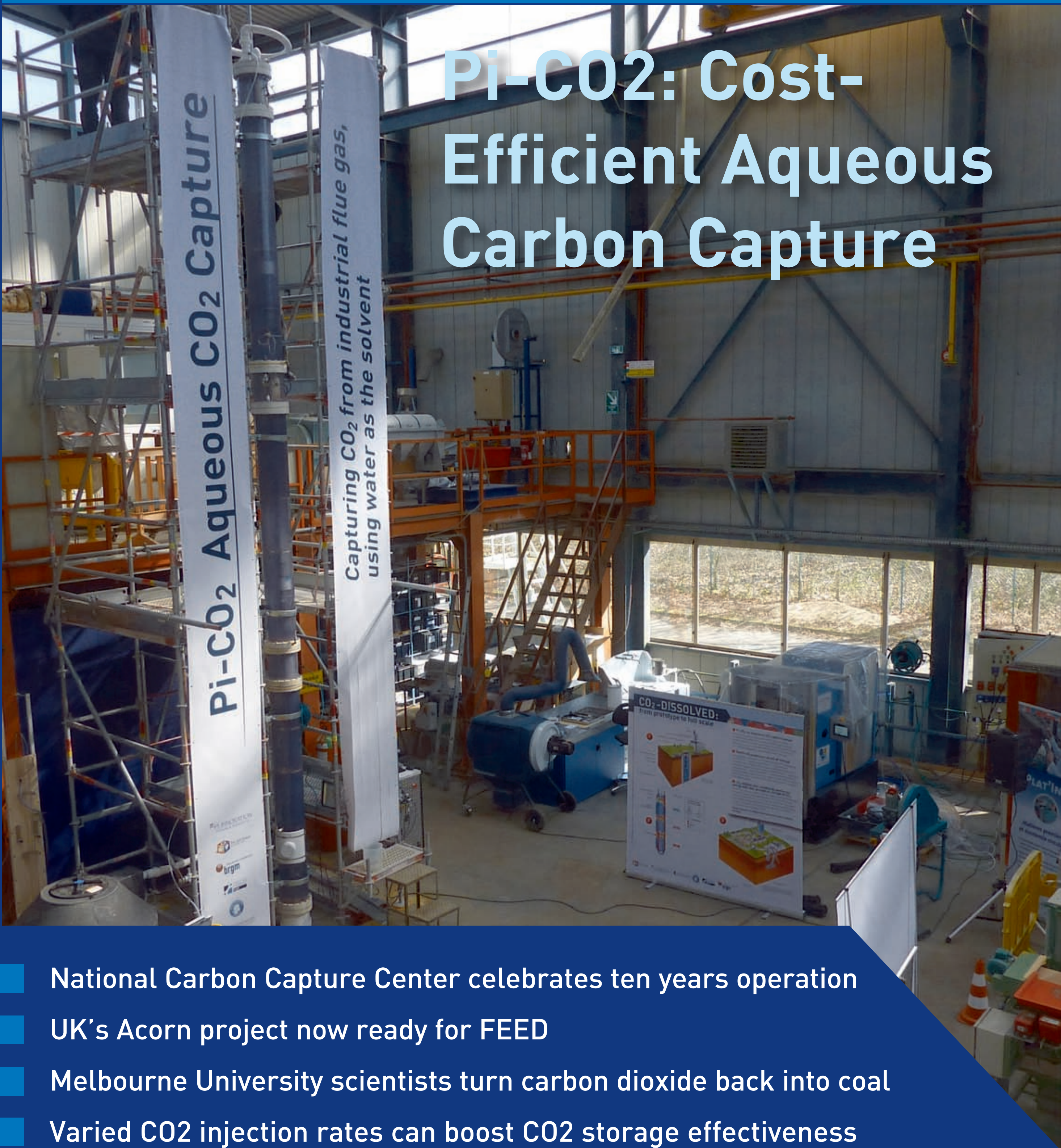

Pi-CO2: Cost-Efficient Aqueous Carbon Capture

National Carbon Capture Center celebrates ten years operation

UK's Acorn project now ready for FEED

Melbourne University scientists turn carbon dioxide back into coal

Varied CO2 injection rates can boost CO2 storage effectiveness

Cost-Efficient Aqueous Carbon Capture: Pi-CO2 Multi-National Prototype

For decades, the limiting condition to CO2 capture has been the 'Cost of Capture'. Over the past 10 years, Partnering in Innovation, Inc. (Pi), Savanah River National Laboratory, and others have developed a low risk system that directly addresses this, and other, limitations.

In 2018, with partnerships in the US and EU, Pi completed their first-of-a-kind prototype demonstrations in collaboration with the BRGM in France.. Also in 2018, the Australia National Low Emission Coal (ANLEC) R&D consortia completed an independent review and Techno-Economic Assessment (TEA) including comparison to an advanced amine system in a 695MW Australian coal-fired power plant.

Under conservative conditions, the TEA reports a total cost of 31/tonne USD (including product compression to pipeline pressures) with feasible design options that may lower total costs to less than $30/tonne.

In addition, Pi-CO2 also offers the potential for the pre-treatment (removal) of contaminants (i.e., SOx, NOx, and Hg) and water recovery in an initial compression step, this added value further reduces total system costs.

The innovation basis is a capture system that uses the well-proven differential solubility of gases in water across variable pressures (Figure 1) to separate and concentrate constituent gas products. The design combines water as a solvent (carbon-neutral, non-hazardous, and non-degrading) with a natural hydrostatic pressure gradient (from atmospheric pressure to higher pressure at depth in a water column) and adds the recovery of compression and heat energy (in a system drawing from Compressed Air Energy Storage or CAES).

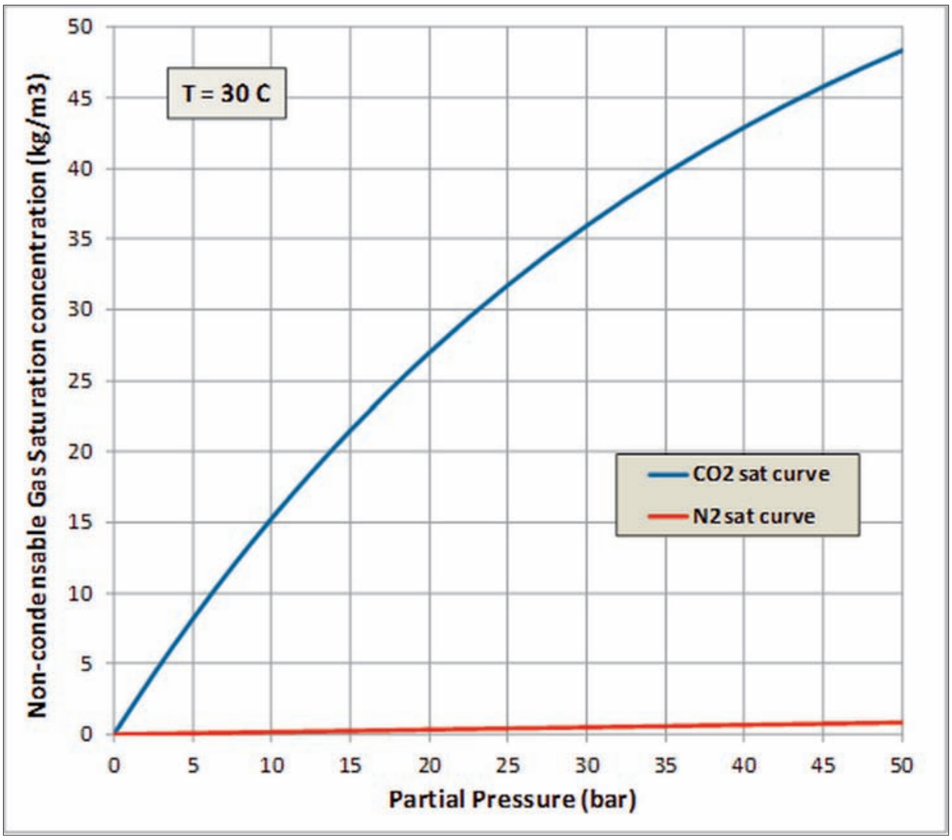

Figure 1 the well-proven differential solubility of gases in water across variable pressures

Techno-Economic Assessment (TEA)

Prior modeling confirmed thermodynamic feasibility and predicted high capture rates (>90%), efficient mass transfer (purity >95%), and high net CO2 reduction. ANLEC R&D and Aurecon Ltd Pty verified these model results and developed a parallel Aspen-PlusV10 model of the system.

The Australian setting (modeled in the ANLEC work) is in some respects a worst-case scenario for Pi-CO2. As just one example, the lack of availability/high cost of natural gas in Australia precluded the use of gas firing in the energy recovery. Even so, the TEA estimated a total cost of CO2 capture (CapEx, OpEx, including product compression to pipeline pressures) of ~31/tonne USD.

Overall, the TEA concluded that Pi-CO2 demonstrated superior benefits in: Cost, Environmental Factors, Ease in Integration, and Overall Energy Balances relative to current state-of-the-art (amine) systems.

Other TEA results suggest that the cost could be further reduced by including supplementary gas firing (in other locations where natural gas is readily available) and, potentially reduced more, by adding catalytic combustion (residual O2 + fuel) in the N2 stream, possibly reducing parasitic energy to as low as 10%.

Valuing the offset of not requiring separate SOx, NOx, and/or Hg pre-treatment systems further reduces the effective cost.

Technology Overview

The core innovation is a patented multi-stage, cascading absorber-desorber column. Adding multiple stages, with co-current flow in each stage and overall counter-current flow, utilizing a bubbly flow regime that enhances mass transfer and overcomes the thermodynamic limits of a single stage.

The concept is elegant in its low complexity (i.e., preferentially dissolving CO2 in water at high pressure) but the

design and fluid dynamics required to efficiently separate a gas mixture within the absorber are quite advanced. The concept draws from bubble, fluid, and mass transfer dynamics from nuclear, wastewater, chemical, and geologic engineering R&D. The pre-treatment steps draw from industrial gas processes and the reduction in parasitic energy is an innovative blend of heat and pressure energy recovery similar to CAES.

In general, the system can be conceptualized as 'above surface', and 'below surface' components (Figure 2). Flue gas is compressed prior to injection (at depth) into the multi-stage column which is suspended in a closed, water-filled shaft or in a deep body of water.

The initial compression step offers the option to integrate SOx, NOx, and Hg removal with minimal additional capital and operating costs. Closed-loop circulation is supported by density pumping, with no moving parts at depth.

The system preferentially dissolves CO2 in water at higher pressures, concentrating it as it moves from stage to stage in the absorber, while concurrently separating the N2.. As the dissolved CO2-enriched water travels back up the column, the CO2 is captured when it rapidly effervesces out of solution at a depth of about 50 meters (i.e., the pressure decreases as it travels up the column, releasing high purity CO2 in an exit line at a specified depth). This effervescence (ex-solution) drives the water circulation via a density buoyancy effect (similar to gas-lift pumping).

The parasitic energy burden is reduced via heat recovery from the initial flue gas compression step and compression energy recovery from the separated N2 gas stream exiting

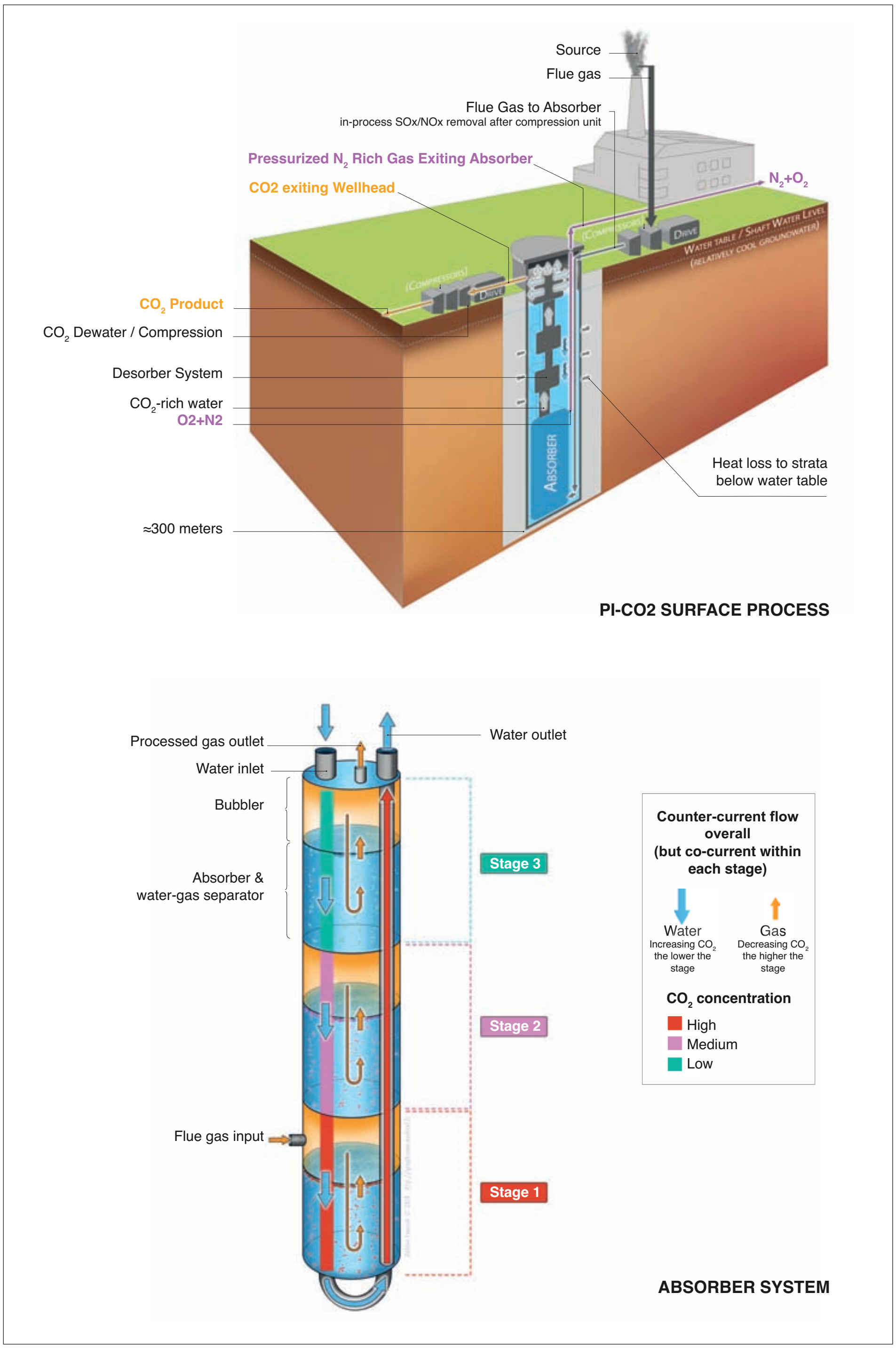

Figure 2: Pi-CO2 Surface and Subsurface System Schematic (© BRGM - Hélène Fournié 2018 http://graphisme-medical.fr)

the absorber in a CAES-like system. The system recovers both water and energy from the flue gas.

The design is low risk as the majority of the components are readily available and well-proven. The first-of-a-kind component is the absorber-desorber column. Even this is based on well-tested precursor concepts including deep shaft reactors (DSRs), down-flow bubble columns, and cascading absorbers. As example, DSRs have been used in large scale water and wastewater treatment plants to mitigate the high energy demands of mass transfer between gas and liquid phases in treatment processes. In addition, two phase natural circulation by a 'gas-lift' effect has been demonstrated in large bore DSRs, eliminating the need for additional pumping.

Some of the key design differences between Pi-CO2 and DSRs include patented features designed to achieve maximum mass transfer with dispersed bubbly downflow and an optimum balance of bubble coalescence in the riser (promoting gas lift). Other unique differences focus on the multiple stages and design parameters enhancing efficiencies.

CO2-DISSOLVED

In parallel, over the past 7+ years, Pi-Innovation has also participated as a core partner in the multi-national CO2-DISSOLVED program led by the BRGM in France (**co2-dissolved.brgm.fr**) and expanded with industry collaboration under a GEODENERGIES co-funded program.

First awarded under a competitive ANR call in 2012, CO2-DISSOLVED is a rigorous R&D program focused on a technical and financial assessment of integrating carbon capture and storage (CCS) with geothermal energy production. In this, CO2 is injected along with the spent brine in a geothermal injection well. The team is in Phase III of the GEODENERGIES program, with a current focus on the design of a pilot test.

Pi-CO2 PrototypeIn 2016, the BRGM co-funded and collaborated with Pi-Innovation and others in the development of two prototypes, one for the CO2-DISSOLVED system and one for the Pi-CO2 capture system.

A goal of the Pi-CO2 prototype testing was to confirm and optimize the design of the multi-stage absorber column. A 3-stage (~9 meters tall) absorber column was constructed in collaboration with The Tech Toybox, Inc. and Make.Work, LLC in Gainesville, Florida.

Figure 3 - Pi-CO2 Prototype in BRGM Laboratory (Image: © BRGM – Rowena Stead)

Prior sensitivity analysis of complex flow (customized code and Drift-Flux model) and thermodynamic (Aspen-Plus) system models indicated key parameters that controlled the energy and mass transfer efficiencies. In terms of the gas-liquid mass transfer in the absorber these included: flow velocity, bubble size, bubble density, and bubble flow regime.

Thus, the tests were designed to measure these parameters and the design was optimized to achieve:

• target ranges matching model prediction of high capture efficiency and product purity, and

• continuous operation with stable flow driven from stage to stage.

The system was tested sequentially – first with one stage, then two (observing flow and bubble dynamics in the transfer between stages) and finally transfer and continuous circulation between three stages. A customized automated data collection and control system provided parameter measurements and data compilation.

The prototype was then disassembled and shipped to France for re-assembly and further testing in the BRGM's laboratory facilities (Figure 3). The tests were successful in all repeated demonstrations, suggesting future success in production scale systems.

Pi-Innovation and current partners are open to expanding partnerships with prospective investors. The next step is a pressurized test of the coupled absorber-desorber, circulation, and product gas capture in a relevant environment prior to pilot testing.

More information

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