GLOBAL CCS INSTITUTE

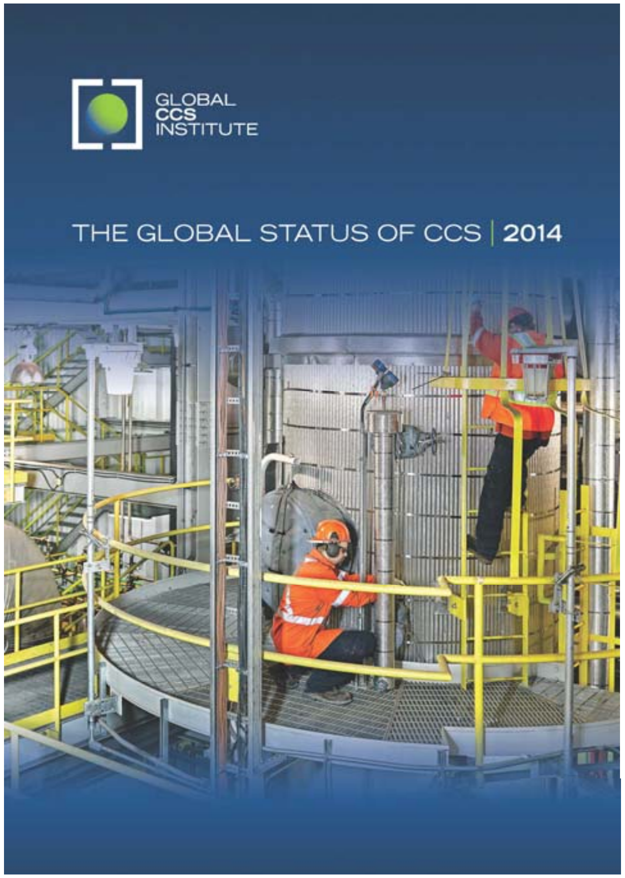
INNOVATIVE WORLDWIDE SOLUTIONS FOR CAPTURE AND USE OF CO_2

SSEB Workshop, Kingsport, TN, 19-20 May 2015

Dr Elizabeth Burton, General Manager – Americas

The Global Status of CCS: 2014

The *Global Status of CCS: 2014* – Key Institute publication



The report:

- Provides a comprehensive overview of global and regional developments in large-scale CCS projects, in CCS technologies and in the policy, legal and regulatory environment.
- Introduces and links to project descriptions for around 40 lesser scale ‘notable’ CCS projects.
- Makes recommendations for decision makers.
- The full report is available online, including supporting resources and data

The Americas Team

- Offices in Washington, DC and Calgary.
- Serving Members in the Americas as well as globally.
- Staff:
  - Dr Elizabeth Burton, General Manager
  - Neil Wildgust, Storage
  - Ron Munson, Capture
  - Pam Tomski, Policy and Regulatory
  - Diane Teigiser, Media Relations and Communication
  - Meade Harris-Goodwin, Capacity Development/Educational Outreach
  - Dr Victor Der, Senior Adviser (part-time)
  - Ellen Brody, Administrative Manager

Americas activities

- Global/Region-wide
  - Advocating for CCS/CCUS
  - Knowledge-sharing among CCS/CCUS professionals; public education
- United States
  - Facilitating the dialog on CCS/CCUS among policymakers, regulators and our Members.
  - Advocacy and facilitation at the state level: PA and CA
- Canada
  - Advocacy at the provincial level.
  - Building public support for projects – school programs.
- Mexico and other Latin America
  - Facilitate progress on CCUS roadmap.
  - Capacity development – professional and graduate training.
  - Facilitate pilot projects.

Mitigation cost increases in scenarios with limited availability of technologies

Percentage increase in total discounted mitigation costs (2015-2100) relative to default technology assumptions – median estimate

2100 concentrations (ppm CO_2eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy
450	138% 4	7% 8	6% 8	64% 8

Symbol legend – fraction of models successful in producing scenarios (numbers indicate number of successful models)

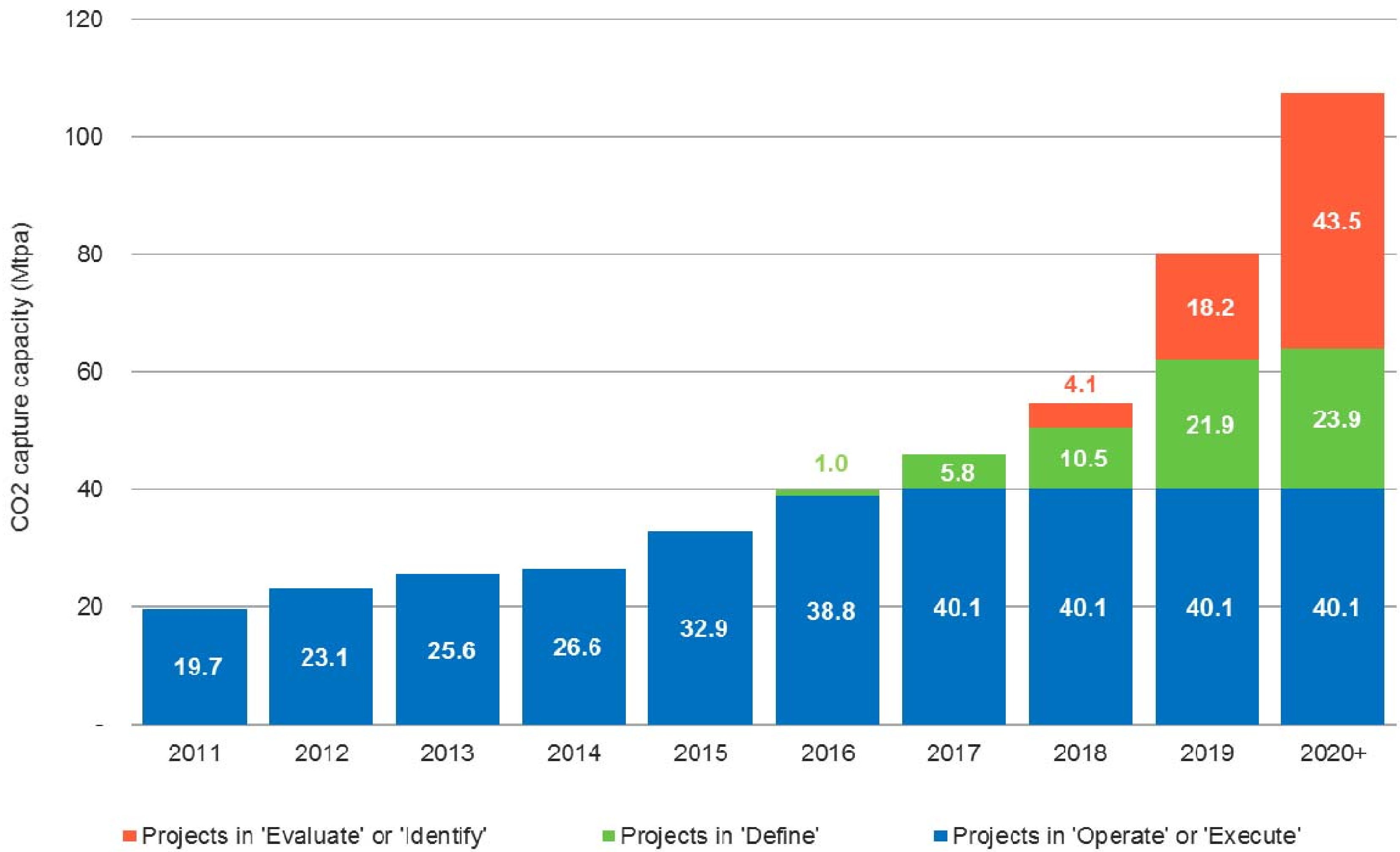
- All models successful
- Between 80 and 100% of models successful
- Between 50 and 80% of models successful
- Less than 50% of models successful

Source: *IPCC Fifth Assessment Synthesis Report, November 2014.*

Large-scale CCS projects

	Early planning	Advanced planning	Construction	Operation	Total
Americas	5	6	6	10	27
China	7	4	-	-	11
Europe	3	4	-	2	9
Gulf Cooperation Council	-	-	2	-	2
Rest of World	4	-	1	1	6
Total	19	14	9	13	55

Capture capacity by year of operation



By 2050, the CCS “wedge” equates to 150 GT stored

Deployment barriers for CO_2 capture

Energy Penalty

- 20% to 30% less power output

Cost

- Increases Cost of Electricity by 80%
- Adds Capital Cost by $1,500 - $2,000/KW

Scale-up

- Current Post Combustion capture ~200 TPD
- 550 MWe power plant produces 13,000 TPD

Capture technology progress

Process improvements and scale-up drive down costs

Laboratory/Bench-Scale

- Simulated operating conditions
-Short duration tests (hours/days)
- Proof-of-concept and parametric testing
- High risk
-0.2 to 1,000 scf per minute

up to 0.5 MWe –> TRL: 2-4

Pilot-Scale Slipstream

- Real operating conditions
- Longer duration tests (weeks/months)
- Lower risk
- 5,000 to 100,000 scf per minute

1.0 to 25 MWe –> TRL: 5-7

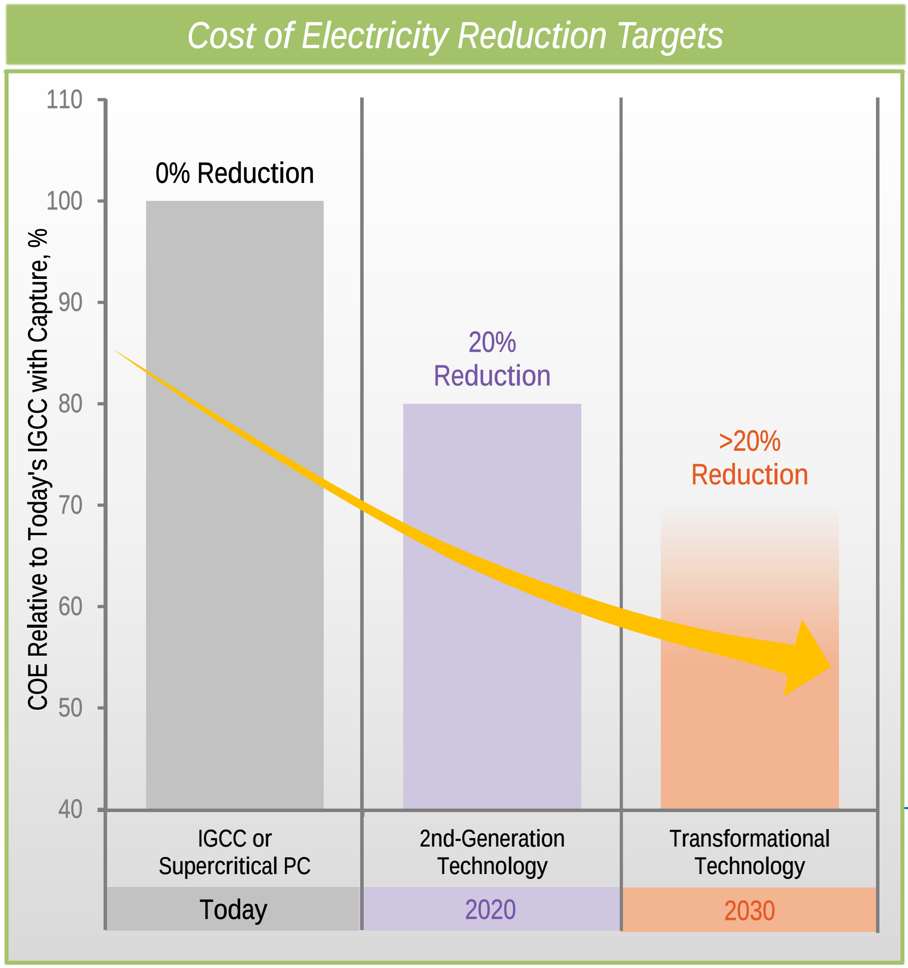
Demonstration-Scale

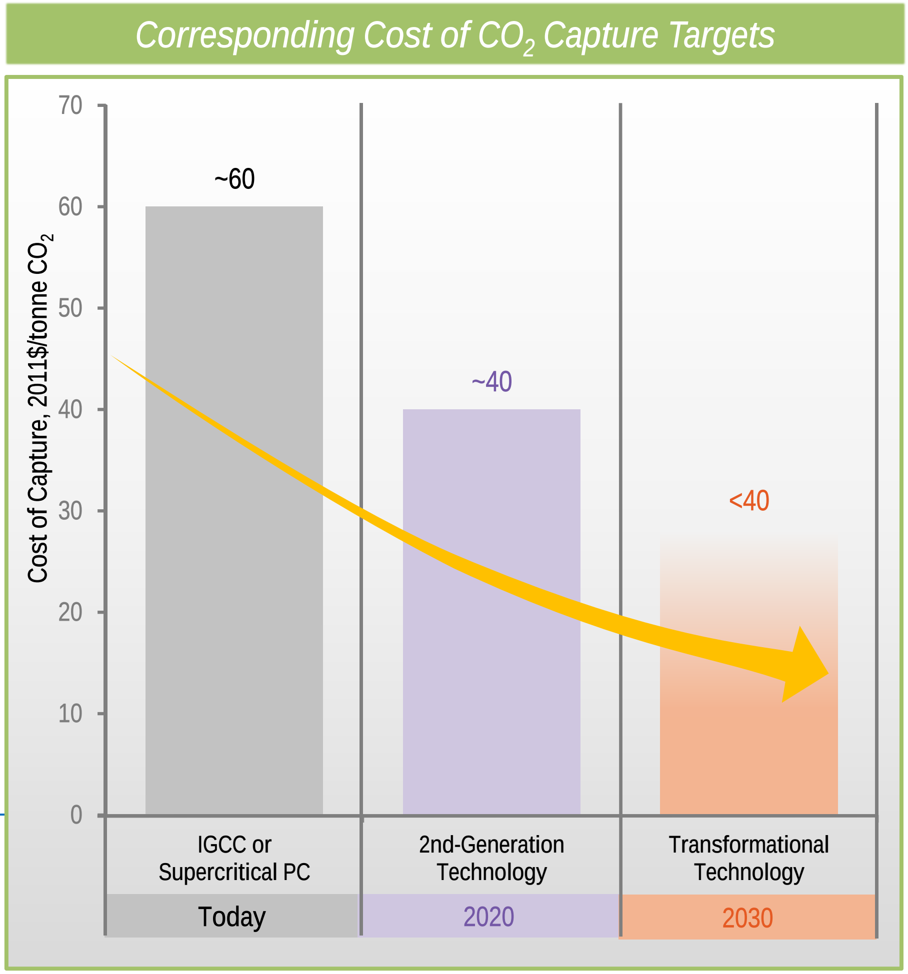
- Variable operating conditions
- Extended duration (typically years)
- Demonstrate integrated full-scale; Minimal risk commercial application
- CO_2 Utilization/Storage

Project(s) – 50 to 500 MWe –> TRL: 7+

Then ***>$100/Tonne*** → ***Now*** ***~$60/Tonne*** → ***Future*** ***<$40/Tonne***

DOE capture cost reduction goals





Shell Cansolv: Boundary Dam amine-based capture system

- Commercial-scale power plant with a fully integrated post-combustion carbon capture system
- 110 MWe coal-fired power production unit
- 90% Capture
- Captured CO_2 is compressed and transported off-site for use in enhanced oil recovery (EOR) operations at a nearby oil field and sent to saline storage (Aquistore)

Current DOE 2nd generation pilot development

Performer	Project Focus	Benefits	Scale	FY 14	FY 15	FY 16	FY 17	FY 18	FY 19	FY 20	FY 21	FY 22	FY 23	FY 24	FY 25	FY 26	FY 27	FY 28	FY 29	FY 30
Solvents																				
Neumann Systems Group	Nozzle-Based Solvent Delivery	Modular; Solvent Agnostic	0.5 MWe																	
Linde	Advanced Amine/ Heat Integration	Single Process Train	1 MWe																	
University of Kentucky	2-Stage Regeneration	High Pressure Regeneration	0.7 MWe																	
Southern Company	Heat Integration/ Exchange	Thermal Management	25 MWe																	
General Electric	Silicone Solvent	Enhanced Energetics	1 MWe																	
ION Engineering	Non-Aqueous Solvent/ Amine Mixture	Enhanced Energetics	0.7 MWe																	
Sorbents																				
ADA-ES	Amine-Based Sorbent	Process Design	1 MWe																	
TDA	Alkalized Alumina Sorbent	Process Cycle	1 MWe																	
SRI	Carbon-Based Sorbent	Attrition Resistance	1 MWe																	
Membranes																				
MTR	Spiral-wound Membrane	Process Design	1 MWe																	
GTI	Solvent Contactor	Process Intensification	1 MWe																	
Oxygen-Fired																				
Aerojet Rocketdyne	Oxy-PFBC	Latent Heat Recovery	1 MWe																	
Alstom	Limestone Chemical Looping Combustion	Inexpensive O_2 Carrier	1 MWe																	

Small Pilot

Large Pilot

Demo

Neumann Systems Group

Project Summary

Approach

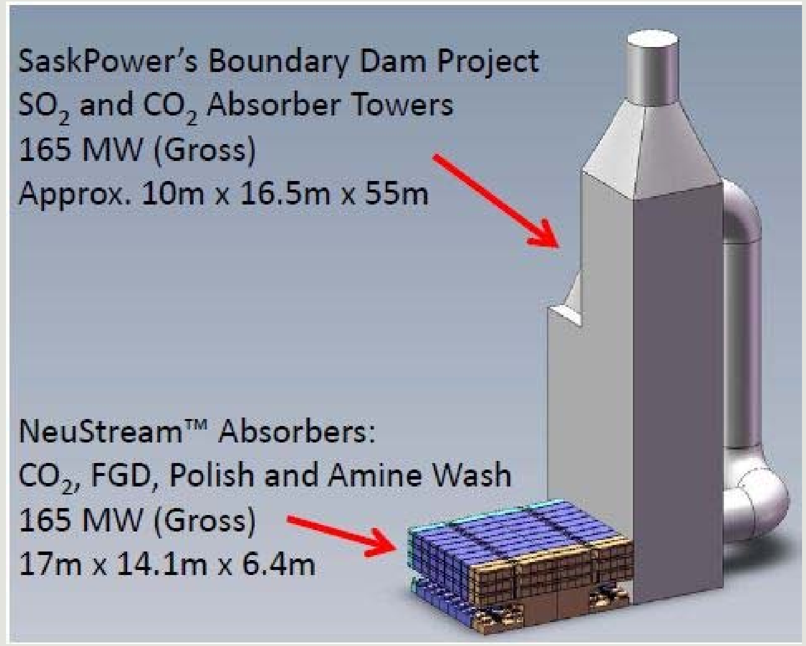
Design and construct a module of the *NeuStream-C* absorber technology Colorado Springs Utilities Drake #7 coal-fired power plant.

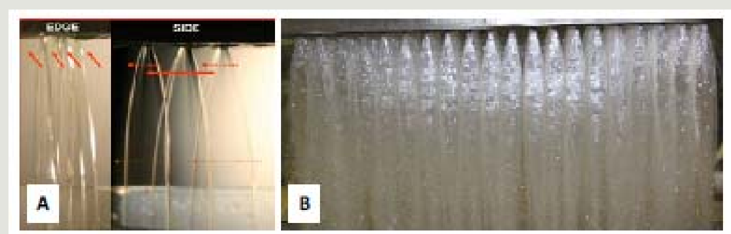
Advantages

- **Significant reduction in absorber capital cost**
- **Compact, modular and scalable gas/liquid contactor**
- **Broadly applicable to solvent-based systems**
- **Novel NO_x control possible**

Challenges

- **Maintaining optimal gas/liquid dispersion in full scale equipment**





Southern Company Services

Project Summary

Approach

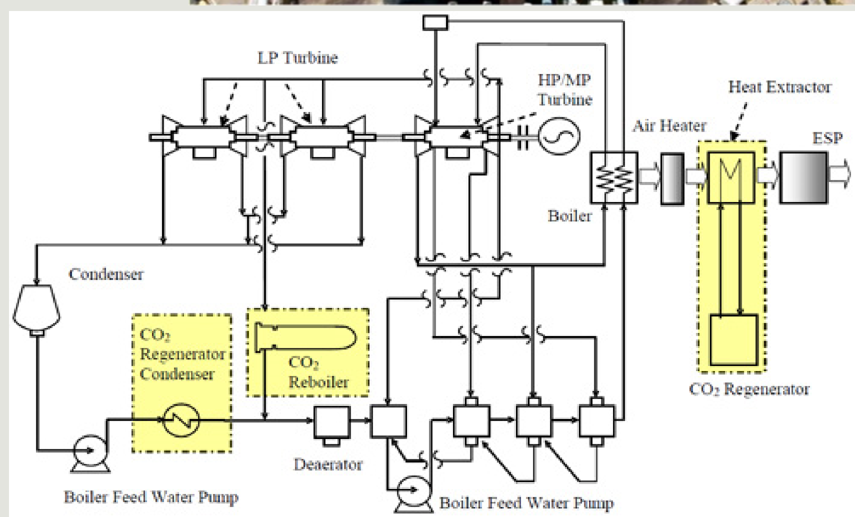
Design, build and install an integrated heat integration system as part of the 25 MWe MHI solvent CO_2 capture system being tested at Southern Company's Plant Barry

Advantages

- **Efficient use of traditionally wasted heat in coal-fired flue gas and captured CO_2**
- **Reduced water use and parasitic energy**

Challenges

- **Control schemes to maintain a proper steam cycle/carbon capture plant heat balance**
- **Developing specific operating parameters and controls to manage the threat of acid gas condensation**



Heat Integration of Power Plant and CCS, Including HES

ADA-ES advanced amine sorbent

Project Summary

Approach

Test ADA-ES's advanced amine-based sorbent technology and process innovations on a 1 MWe slipstream at Southern Company's Plant Miller

Advantages

- **High working capacity**
- **Low heat capacity minimizes heat input needs**
- **Reactor design (CFB) alleviates pressure drop**
- **Fundamental sorbent chemistry is well-known**
- **Components of process equipment are mature**

Challenges

- **Long-term stability of sorbent**
- **Ability to control sorbent temperatures and counteract changes resulting from the heat of reaction, potential erosion, and/or corrosion of process equipment**

Linde and BASF

Project Summary

Approach

Test BASF's advanced amine-based solvent process technology and Linde's novel equipment and process innovations on a 1 MWe slipstream at the National Carbon Capture Center

Advantages

- Solvent more stable, higher capacity, faster kinetics and ~30% lower energy demand than MEA
- Projected up to 60% lower electrical energy load
- Novel intercooler
- Integrated absorber/wash unit
- High pressure regeneration
- Low cost materials of construction (projected ~30% capital savings)

Challenges

- Sustaining performance projections through scale up

MTR

Project Summary

Approach

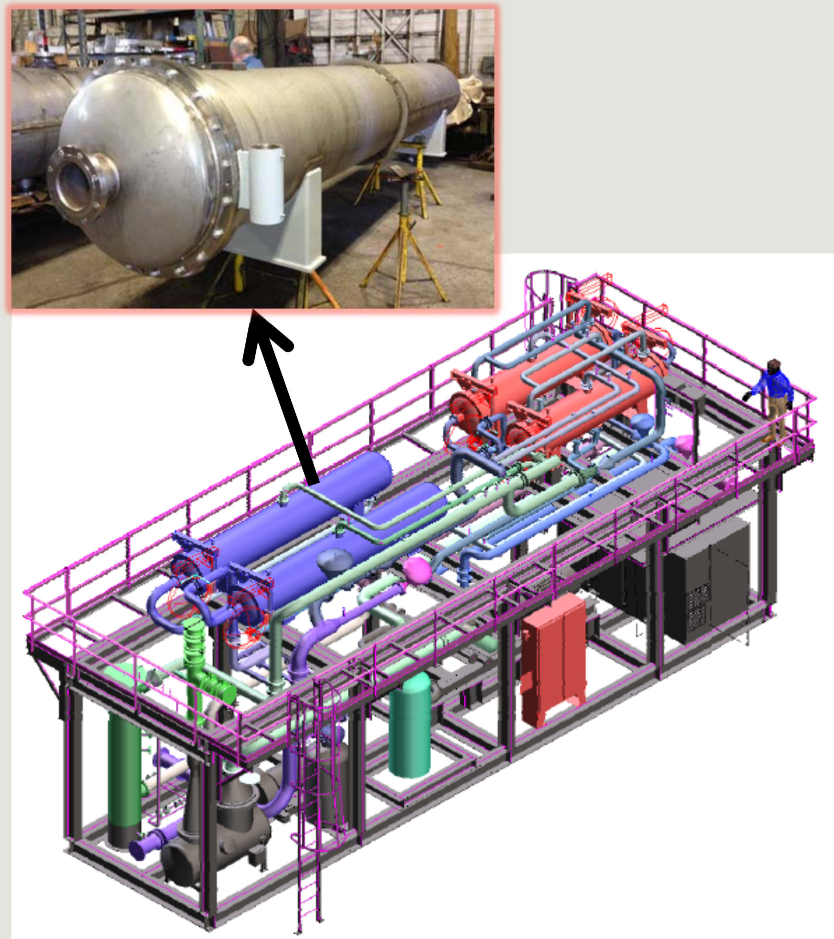
Develop and test a spiral-wound membrane process on a 1 MWe slipstream at the National Carbon Capture Center

Advantages

- Compact equipment
- Smaller footprint
- Efficient scale-up 20-25x larger than current modules
- Capital cost reduction
- Reduced process complexity

Challenges

- Overcoming sweep side pressure drop
- Effective use of all membrane area
- Maximizing packing density while minimizing pressure drop



AEROJET ROCKETDYNE: Fluidized bed combustion

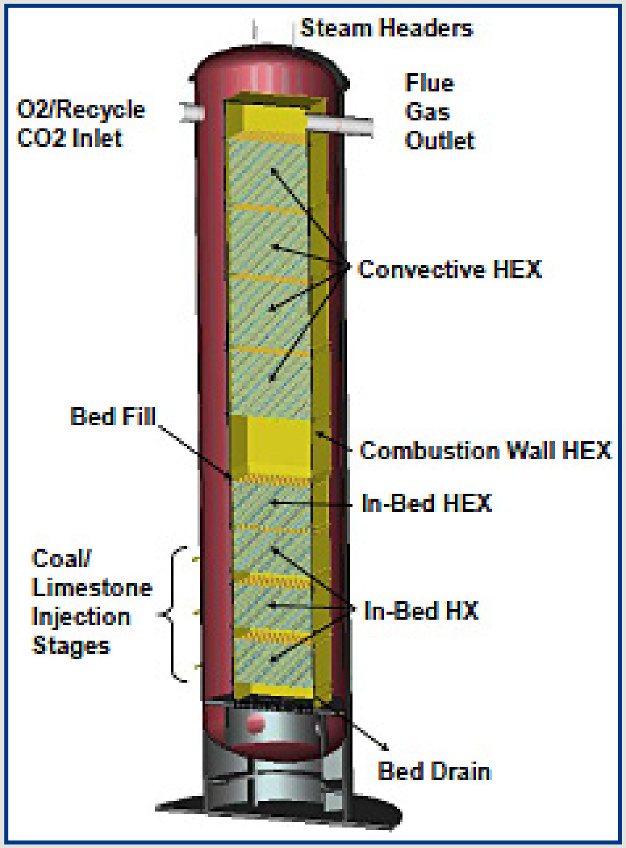
Project Summary

Approach

Develop and test the pressurized fluidized bed combustion concept and validate associated models with a 1 MWe unit operated at CANMET facilities.

Advantages

- **Combines best features of atmospheric CFB and bubbling fluidized bed technologies in smaller package**
- **Predictable behavior over very wide range of flow rates**
- **Constant temperatures throughout bed**



Challenges

- **Achieving appropriate reaction rates**
- **In-bed heat exchange**

ALSTOM: Limestone chemical looping

Project Summary

Approach

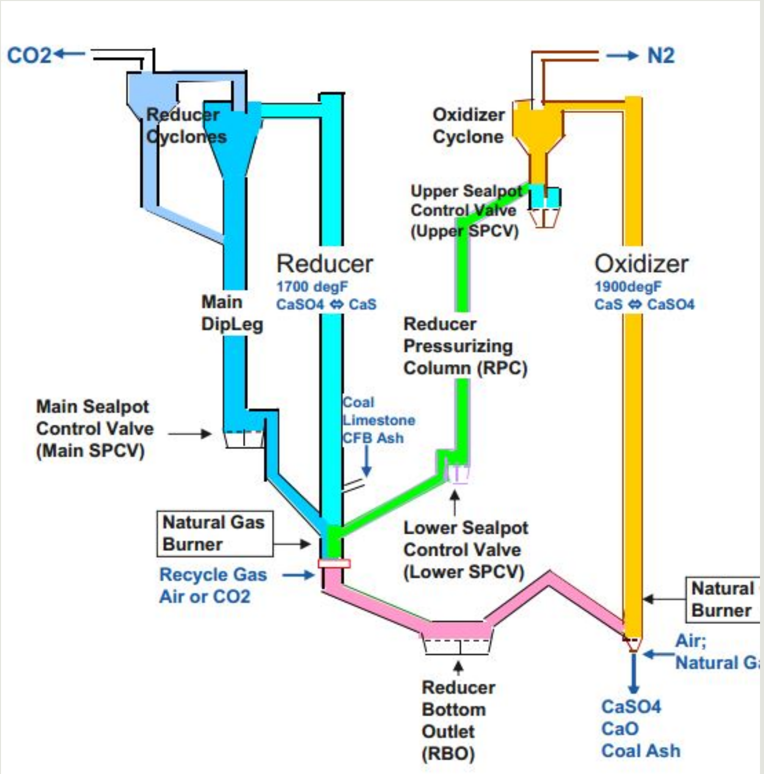
Address technology gaps to improve and optimize the Limestone Chemical Looping Combustion (LCL-C™) process through operation of a 1 MWe prototype system

Advantages

- **Air separation unit (ASU) is not required for oxygen production**
- **CO_2 separation takes place during combustion**
- **Alternate process configurations for both combustion and gasification**
- **Low-cost limestone carrier**

Challenges

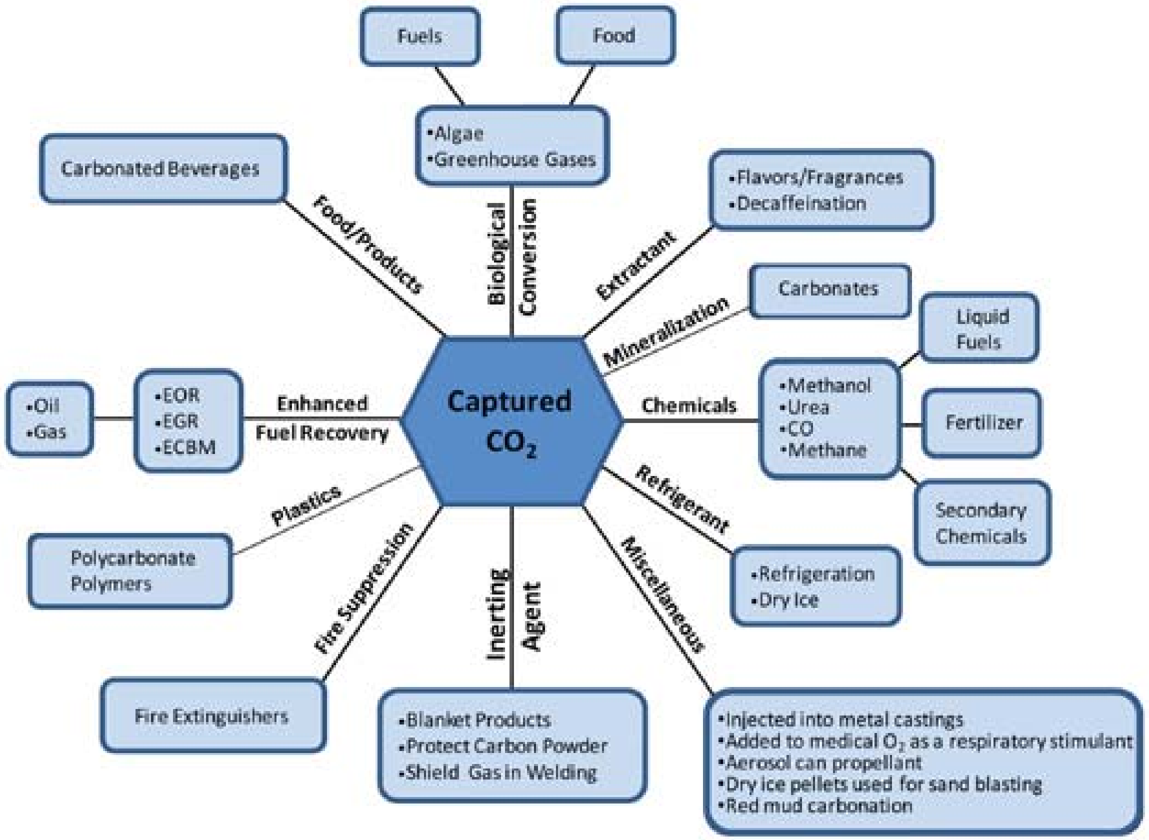
- **Scale-up**
- **Solids handling and transport**
- **Oxygen carrying capacity and reactivity**



Utilization Can Change the Outlook for CCS

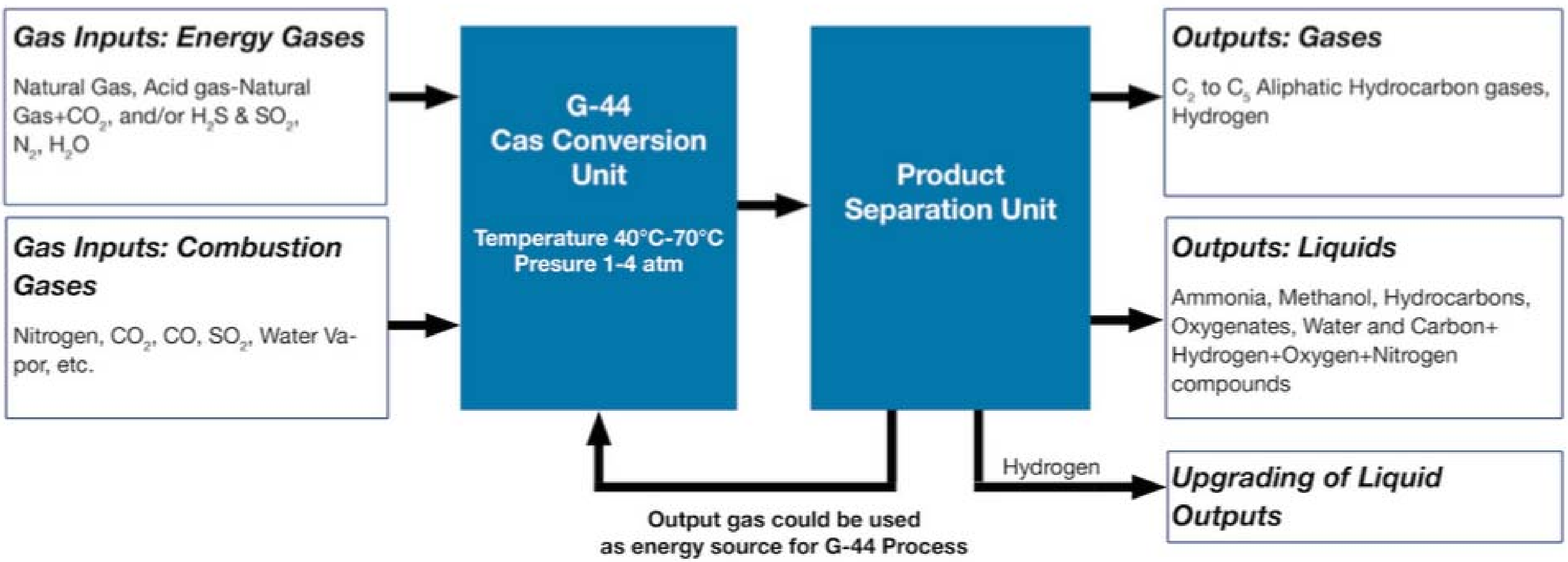
Putting in the "U" may

- Improve project economics if high revenue, high volume product
- Create local support and positive perceptions
- Create permitting challenges
- Create storage verification challenges



Catalytic Conversion of CO_2 to Fuel/Chemical Precursors

- **Multiple approaches under development**
  - Precious metal catalysts
  - Innovative catalysts (eg., amorphous p-type chemical semiconductor catalysts)
  - Others
- **Some pilot testing completed**
- **Promising Economics**
- **Scale-up necessary**



CO_2 Utilization - Microalgae

Project Summary

Approach

Pilot-scale testing at multiple sites

- **180 tpd, algae for biofuel at Ratchaburi Power Plant (Thailand)**
- **700 tpa, Algal synthesis, Tarong Power Station (Australia)**
- **50,000 tpa ethanol, China Steel Corporation (Taiwan)**
- **1 tpd Algae Photo-Bioreactor Duke Energy, East Bend Station, Univ. of Kentucky**

U of Kentucky pilot-scale photo-bioreactor tubes

Advantages

- **Some modular and scalable**
- **Value-added products (bio-fuel, chemicals & food products)**

Challenges

- **Scale-up**
- **Algae viability/degradation**

China Steel Corporation ethanol plant
Feed gas: CO2+CO+H2
Blast furnace gas (BFG), basic oxygen furnace gas

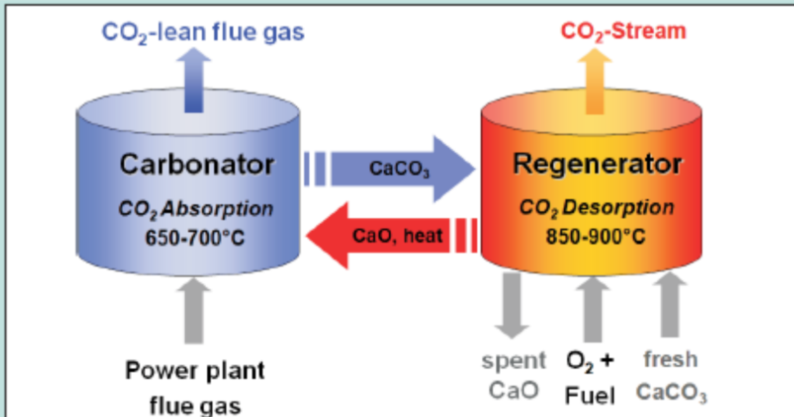
Calcium looping

Project Summary

Approach

Pilot-scale testing at multiple sites to support scale-up

- **1 MWth at TU Darmstad (GE)**
- **200 kWth at University Stuttgart (GE)**
- **1.9 MWth at ITRI (Taiwan)**



√ Calcium Looping is a post-combustion CO_2 capture technology
√ Sorbent utilized is CaO
√ CO_2 is captured in carbonator ($CaO + CO_2 \rightarrow CaCO_3$)
√ CO_2-rich gas is released from regenerator and ready for storage ($CaCO_3 \rightarrow CaO + Co_2$)

Advantages

- **High capture rate (>90%)**
- **Heat integration opportunities to enhance efficiency of associated power generation facility**

CaO sorbent particles

Challenges

- **Energy requirements**
- **Solids handling and transport**
- **Sorbent attrition**

KEPCO – dry sorbent

Project Summary

Approach

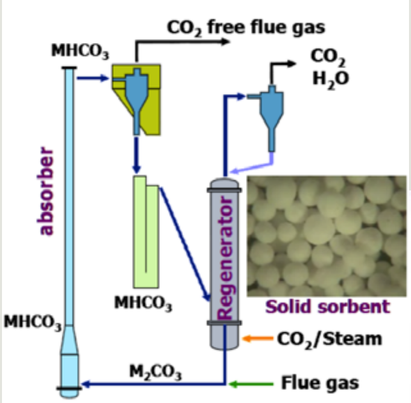
Test KEPCO's carbonate-based sorbent technology and process innovations on a 10 MWe slipstream at KEPCO's Plant Hadong

Advantages

- **High sorption capacity**
- **Minimize influence of water & pollutants**
- **Good regenerability**
- **Utilization of waste heat**
- **Low specific heat capacity**

Challenges

- **Sorbent attrition**
- **Presence of liquid water**
- **Emergency shutdown**



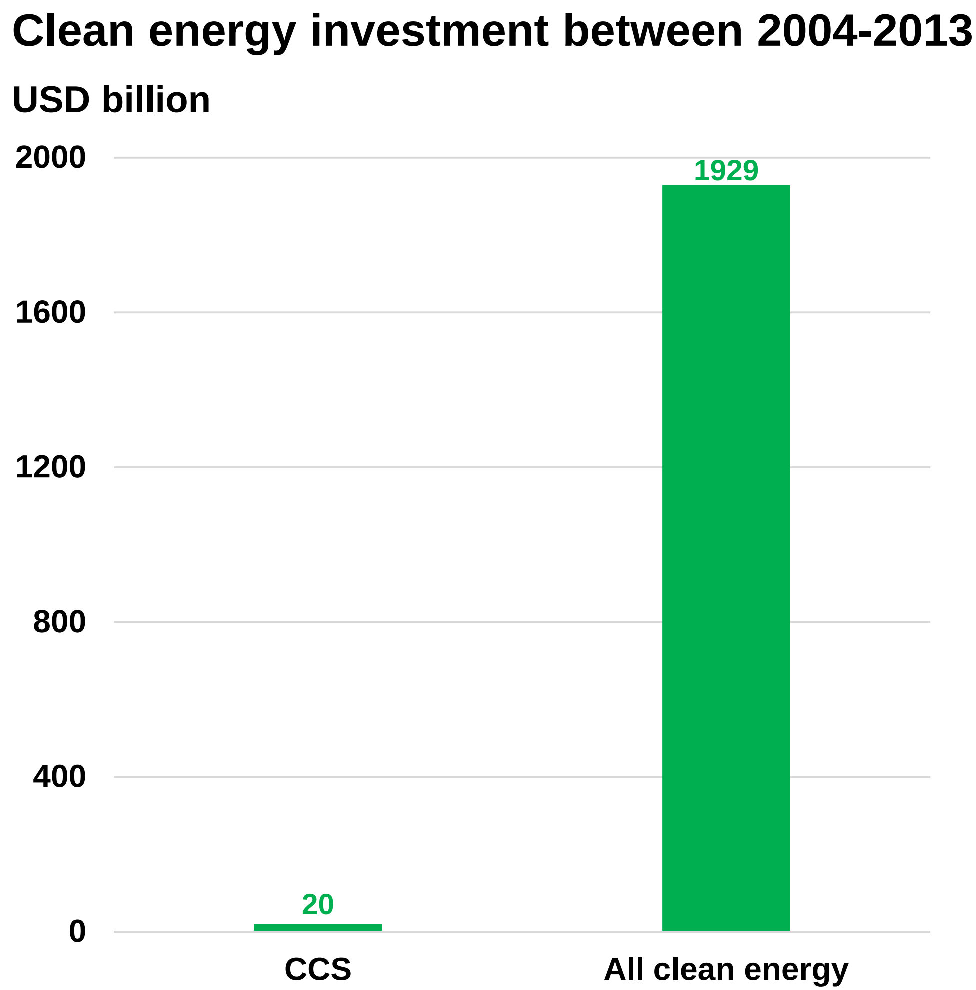
Process schematic of KEPCO dry sorbent process

KEPCO – Hadong Thermal Power Station 10MWe Pilot Plant

Reference: Chong Kul Ryu, KEPCO, CSLF Forum 2014

Strong policy incentives drive investment

- Scale of renewables investment is instructive
- CCUS has not enjoyed commensurate policy support
- EOR has provided impetus in North America
- Policy parity is essential
- How do we get CCUS onto a similar curve?



Data source: Bloomberg New Energy Finance as shown in IEA presentation "*Carbon Capture and Storage: Perspectives from the International Energy Agency*", presented at National CCS week in Australia, September 2014.

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