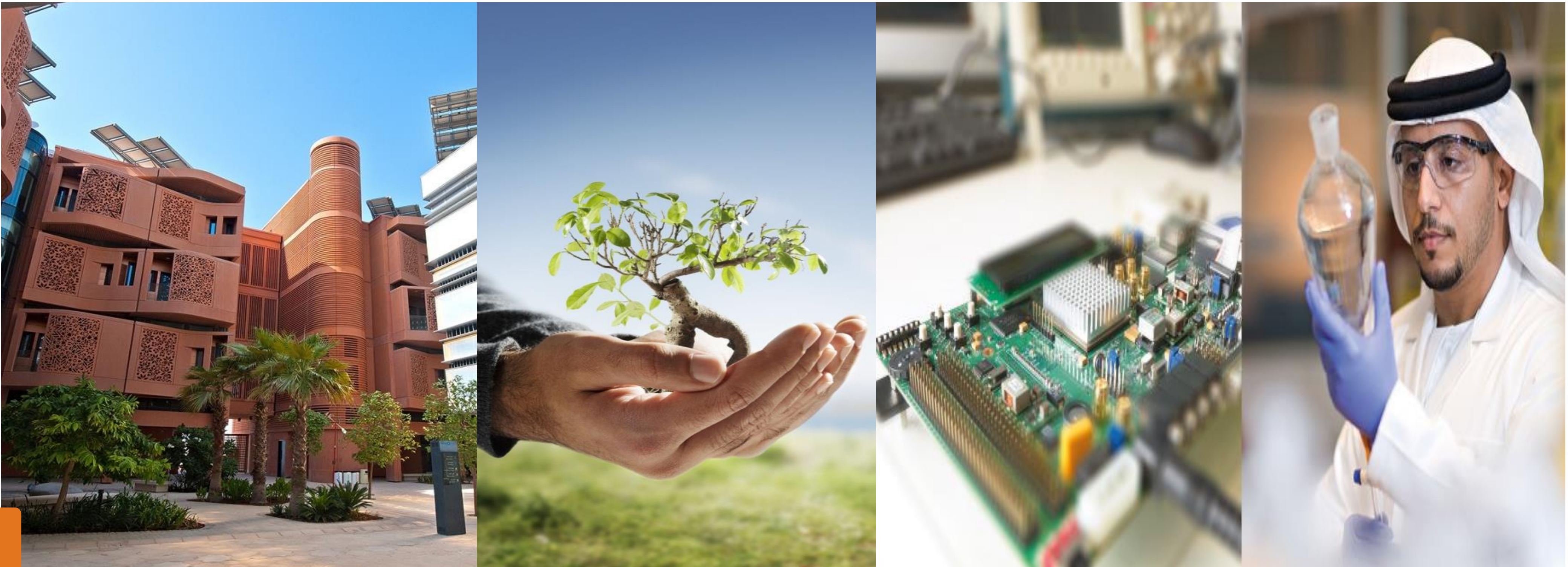
In collaboration with Massachusetts Institute of Technology

Masdar INSTITUTE



# CCUS R&D Status and Potential in the UAE

**Mohammad Abu Zahra,** **Department Head Chemical and Environmental Engineering, CCUS Coordinator**

UN ESCWA Workshop on Deployment of Carbon Capture, Use and Storage in the Arab Region: Challenges and Opportunities
February 19, 2017, Manama, Bahrain

# Intended Nationally Determined Contributions (INDC's)

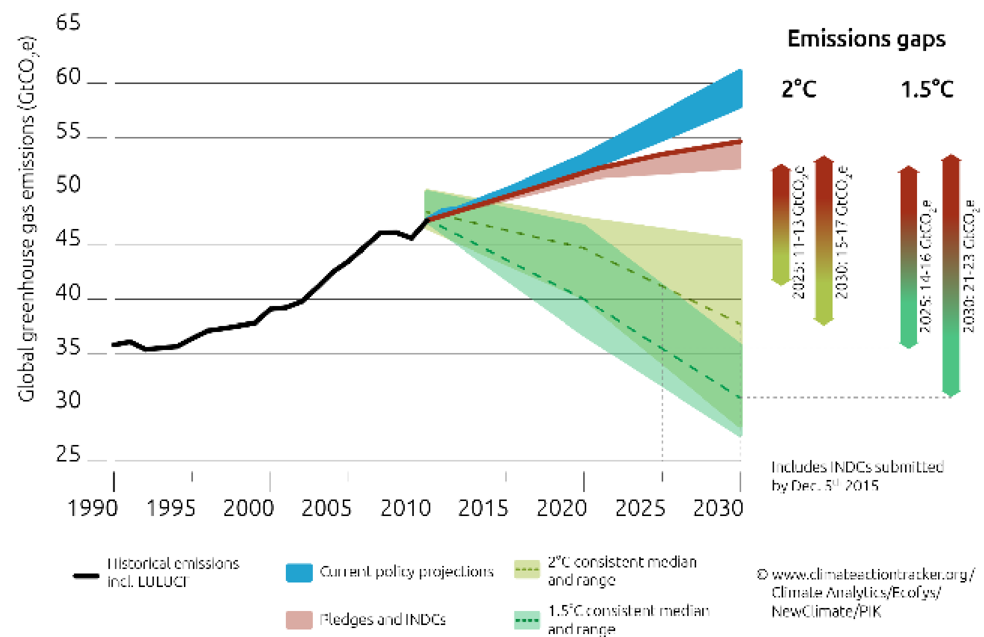
- 187 INDCs submitted
- 94% global emissions
- New trajectory to ~ 2.7C
- ~ 3.6C from existing policies
- CCS in 10 INDCs:

| | |
|---|---|
| **Bahrain** | Malawi |
| Canada | Norway |
| China | **Saudi Arabia** |
| Egypt | South Africa |
| Iran | **UAE** |

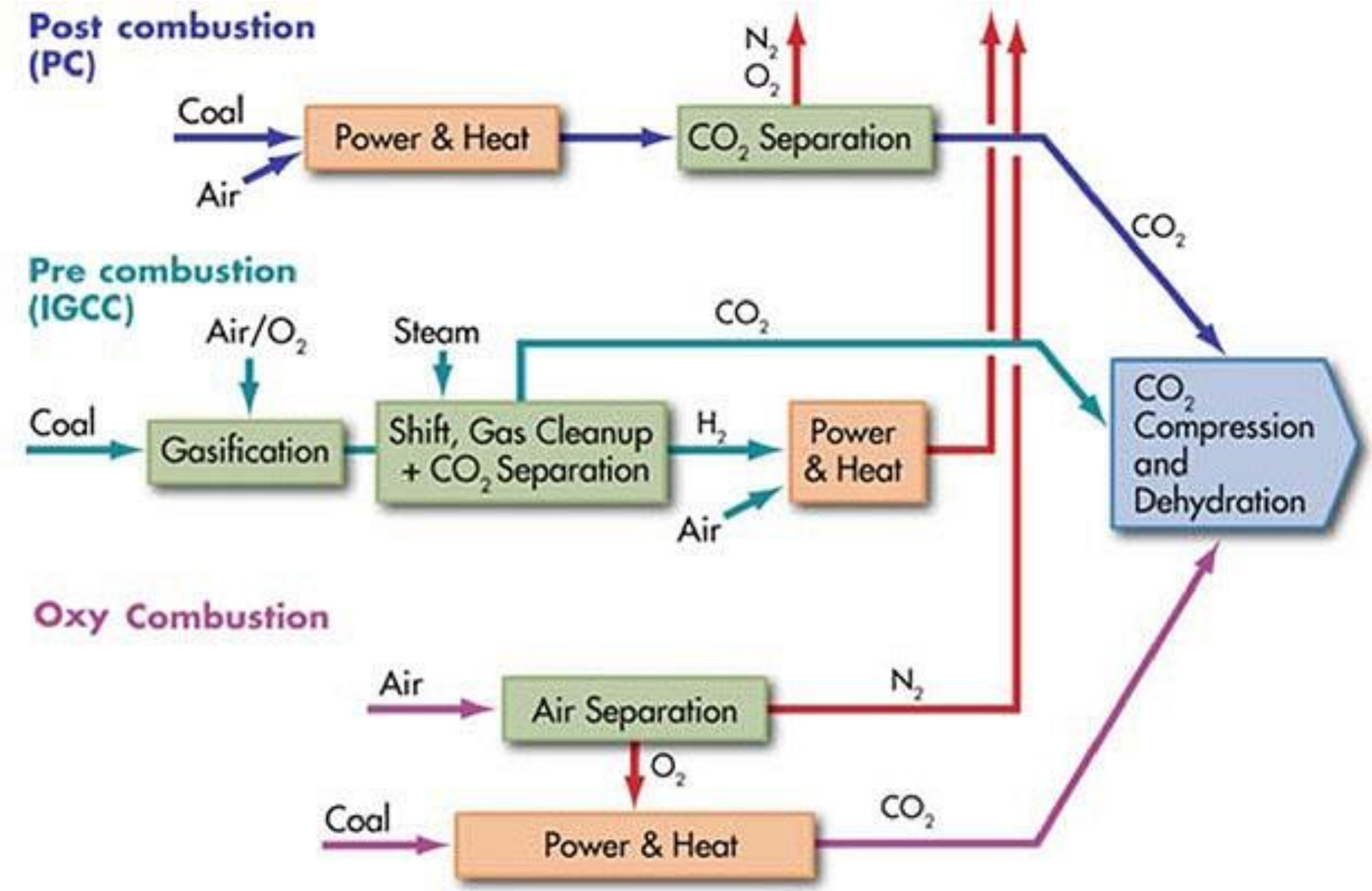
(and EU)

CAT Emissions Gaps

7th December 2015



# Carbon Capture Technologies Status



# Post Combustion Capture

- Significant progress in reducing energy of regeneration for amine based process
  - Now 2.0-2.3 MJ/Kg $CO_2$, Cansolv 201 solvent, +others, Down from 4-4.5MJ/Kg in 1990
- Significant number of vendors testing or tested at 10MW - 100,000t scale
  - TCM – Cansolv, Aker, Carbon Clean Solutions, ….
  - Shand – Hitachi
  - Shanghai – Huaneng Group
  - Tomakomai – MHI
- Many more at 1-2MW scale - NCC

# Post Combustion Capture Developments

## Boundary Dam 3, Canada

- Refit of existing coal fired unit
- Operational for 1 year
- CanSolv amine based PCC technology
- 110MWe
- 95% capture
- $CO_2$ sold for EOR

## NRG Parish, USA

- Refit of existing coal fired unit
- Operational  in late 2016
- MHI amine based PCC technology
- 250 MW slip stream
- 90% capture
- $CO_2$ sold for EOR

# Post Combustion Capture

- Boundary Dam 3 Operational Achievements
  - March 2016 - a 90% reliability factor had been achieved for the first quarter of 2016
  - July 2016 – 1 millionth tonne of $CO_2$ had been captured
- Cost reduction from learning by doing
  - 30% CAPEX, 25% OPEX
- A capture technology must be piloted at a scale that allows for reasonable engineering scale up to a commercial size”

# Oxy Fuel Combustion

## Alstom/GE

- 35MWth test facility at Schwarze Pumpe, Germany
- Engineering design for White Rose 426MWe (gross) – now cancelled

## B&W

- 30MWth Burner tests, Ohio, USA
- Engineering design for FutureGen 2.0 159MWe project – now cancelled

## HUST, China

- 35MWth test facility in Wuhan, China
- Lead to a 200MWe FEED design

# Pre-Combustion Capture

- Rectisol and Selexol capture technologies are commercially proven
  - ➢Rectisol process in operation at Dakota Gasification facility since 2000
  - ➢Selexol process to be demonstrated at Kemper County in late 2016
- Osaki CoolGen Project - IGFC
  - ➢166 MW oxygen-blown IGCC to operate in 2017-18
  - ➢Add an amine based capture test facility , 2019 on
  - ➢Add MCFC – 47-49% cycle efficiency

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## $CO_2$ Capture - Novel Systems

- Substantial body of technical literature published
- Many systems are proven on lab and small scale
- Potential of cost savings and reduced energy penalties
- Technical readiness increased
  - Chemical/calcium looping, solid sorbents and polymeric membranes
  - Require technical proofing at pilot scale and above

# Industry CCS

CCS is now deployed in:

- Natural gas upgrading – mostly amine based technology (Sleipner, Snohvit, Gorgon …)
  - Game changer – Membrane technology for Lula project, offshore Brazil
- Hydrogen refining/upgrading
  - Quest – solvent based technology
  - Air Products, PSA technology
- Steel sector
  - Emirates Steel – Amine based capture

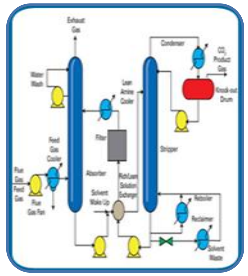
# CCUS R&D Activities Overview at Masdar Institute

## Importance for Abu Dhabi

These activities contribute to the overall vision of Abu Dhabi to reduce GHG emissions. One of the approaches to reduce carbon emission is by the development and deployment of CCS technologies. The current R&D projects will encourage the deployment of CCS technology in UAE. Having the advantage of being an oil producing country, CCS in the UAE will serve to be an excellent candidate to allow for enhanced oil recovery.

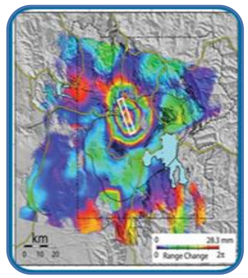
## Researchers

Dr. Mohammad Abu Zahra
Prof. Toufic Mezher
Prof. Mohamed Sassi
Dr. Enas Nashf
Dr. Ahmed Al Hajaj
Dr. Khalid Al Ali
Prof. Tariq Shamim
Dr. Hosni Ghedira
Dr. I-Tsung Tsai
Prof. Taha Ouarda



## $CO_2$ Capture Technologies

- The development of novel capture systems and processes for post-combustion capture, hydrogen production and chemical looping.
- Multiple projects were established in collaboration with Siemens, MIT, Masdar Carbon and RTI.



## $CO_2$ storage, injection and monitoring

- Study the interactions between the injected $CO_2$ and the brine saturated rock, geo-chemistry, geo-mechanics, and trapping phenomena during $CO_2$ storage
- $CO_2$ monitoring (GPS and INSAR)
- Collaboration with MIT, ADNOC, ADCO and PI


## CCS Policies and Regulations

- Optimal $CO_2$ regulation to Align CCS with EOR and CDM
- Energy Policy and Technology Strategy and scenarios
- Risk analysis, CCS economics and regulations

# Siemens-Masdar Institute Collaboration

SIEMENS

This long term collaboration is aiming to the development of $CO_2$ post-combustion capture technologies, which suitable for deployment in the gulf region. With major focus on Siemens PostCap technology

**Supporting Masdar Institute post-combustion capture activities by:**

- Siemens fellowship program (**Master and PhD students**)
- R&D projects concluded in 2015

**Coordinator**
**Dr. Mohammad Abu Zahra**
mabuzahra@masdar.ac.ae

**Evaluation of $CO_2$ Purification Requirements and Techno-Economic Evaluation of Processes for Impurities Deep Removal from the $CO_2$ Product Stream**
**Concluded in May 2012**

**Evaluation of handling approached of solid waste generated from the POSTCAP process considering the regulations in UAE**
**Concluded in April 2013**

**Contactor Design for Hybrid Systems for $CO_2$ Capture**
**Concluded in July 2014**

**Liquid Fuels Evaluation and Characterization**
**Concluded in June 2015**

# Testing and Evaluation of $CO_2$ Capture and Utilization

**Research Team:**
**Dr. Mohammad Abu Zahra (PI)**
**Dr. Ahmed Al Hajaj (Co-PI)**
**Dr. Quang Dang (Researcher)**
**Abdallah Dindi (PhD Student)**

Solutions In Engineering Technologies

Total project budget: $ 900,000
Project Duration: 30 months

### Project Overview

This project is to test and evaluate the possible application of fly ash and modified fly ash for capture and utilization of $CO_2$ from flue gas. Overall experimental testing and techno-economic evaluation modelling will be conducted for this CCU technological options.

The integration between this technology and desalination plants is feasible through the use of reject brine. The possible combination of fly ash with reject brine from desalination plants for $CO_2$ sequestration will be investigated by this project for the GCC region.

### Impact & Objectives

- To evaluate the possible application of fly ash and modified fly ash for capture and utilization of $CO_2$ from flue gas. The possible combination of fly ash with rejected brine from desalination plant for $CO_2$ sequestration will also be investigated.
- To carry out a detailed techno-economic evaluation of the proposed ZCF based $CO_2$ capture technology.
- Support ENGSL in the testing and evaluation of use of caustic soda and sodium silicate solution for capture and utilization of $CO_2$ from flue gas to produce soda ash and Amorphous Precipitated Silica (APS).

### Key Outcomes

- Feasibility study and techno-economic evaluation of the proposed ZCF based $CO_2$ capture technology.
- Develop and evaluate fly ash-based advanced sorbnet for $CO_2$ capture applications.
- Evaluate and test potential utilization of $CO_2$ from flue gas to produce soda ash, Amorphous Precipitated Silica (APS) and other materials from the fly ash.

# Study of CCUS Integrated Concept at Mirfa Plant Including Oxy-Fuel Combustion

MAERSK OIL

Research Team:
Dr. Mohammad Abu Zahra (PI)
Dr. Ahmed Al Hajaj (Co-PI)
Alia Al Jasmi (MSc Student)
Vinicius Bueno (MSc Student)

**Project Overview**

The general concept of this project is to evaluate the concept to utilize the available oxygen on Mirfa plant site for power generation. In addition, a multi-purpose integration of different processes, such as power generation, carbon dioxide capture, water desalination and $CO_2$ utilization for enhance oil recovery.

This research aims to perform a high-level evaluation focusing on the available oxygen utilization opportunities for power production and integrate it with different $CO_2$ capture process. Finally, it will define the related technical potential and challenges in the overall concept and in the individual processes.

**Impact & Objectives**

- The project is designed to deliver a high level techno-economic evaluation of the overall integrated concept with major focus on the products utilization opportunities, technical and operational challenges, technologies level of maturity and areas of potential improvement and research requirement.
- Secondly, the project will evaluate the feasibility of different process schemes those will utilize the available oxygen stream for power production and integrate it with different $CO_2$ capture process options.

**Key Outcomes**

- Overall process concept (block diagram) and the boundaries for the techno- economic evaluation
- Evaluate different power production, $CO_2$ capture and products utilization schemes with major focus on the power generation and the carbon capture islands.
- Define the related technical potential and challenges in the overall concept and in the individual processes. This will be linked to the technologies level of maturity and the need/potential for research and development

# Development of New Sorbents Systems for $CO_2$ Post-Combustion Capture

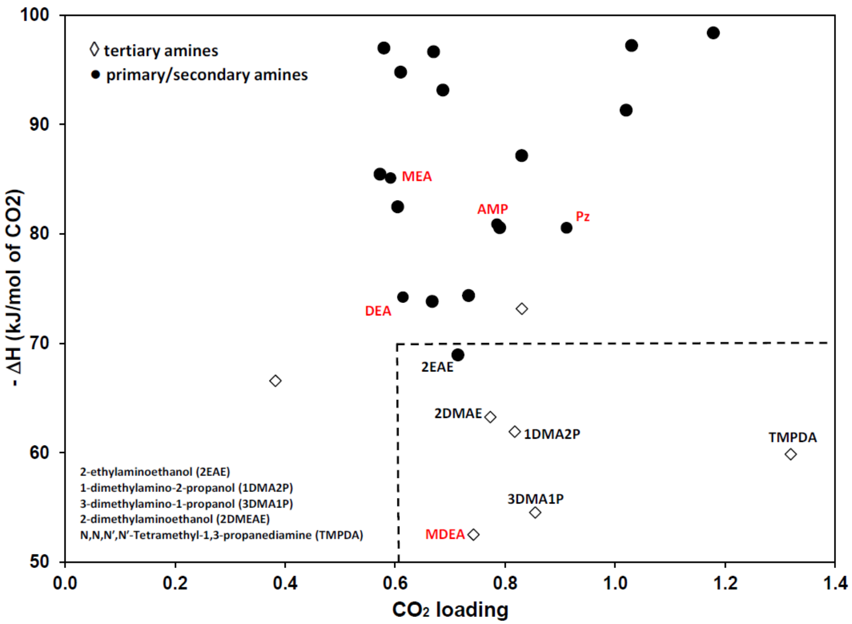
- Development and characterization of $CO_2$ capture sorbents for post-combustion capture application
- Developing $CO_2$-binding organic sorbents for $CO_2$ post combustion capture.
- Systems developed include: amine-based, organic based and deep eutectic solvents (DES's)

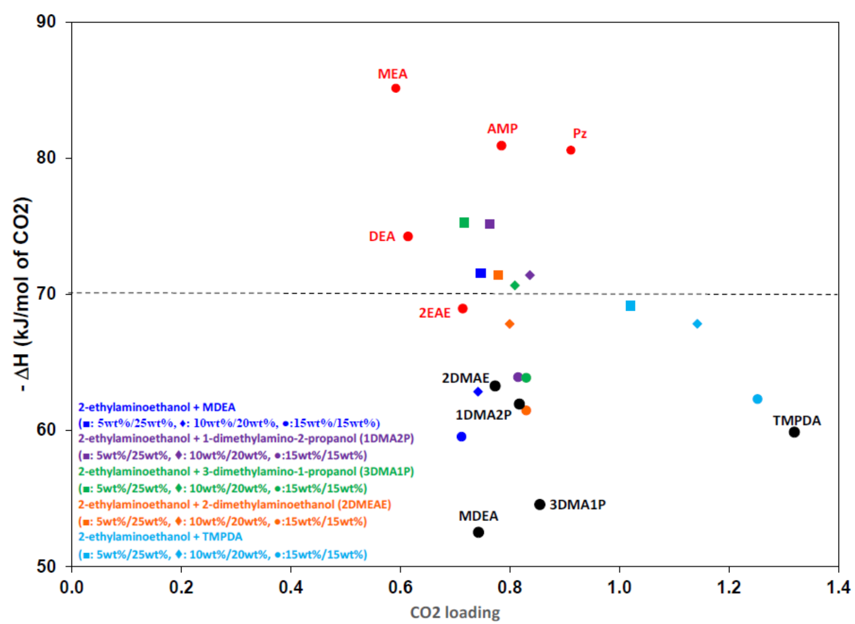
**Faculty**

Dr. Mohammad Abu Zahra (MI);
Dr. Enas Nashef
Prof. T. Alan Hatton (MIT)

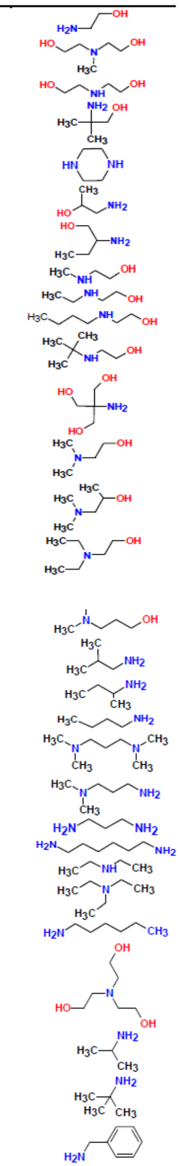
# Novel Aqueous Systems Screening and Results

Massachusetts Institute of Technology



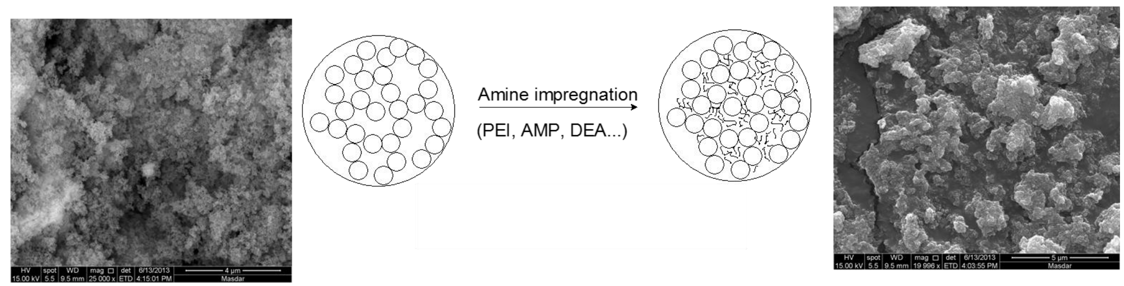




| | Name | Structure |
|---|---|---|
| 1 | Monoethanolamine (MEA) | |
| 2 | N-methyldiethanolamine (MDEA) | |
| 3 | Diethanolamine (DEA) | |
| 4 | 2-amino-1-methyl-2-propanol (AMP) | |
| 5 | Piperazine (Pz) | |
| 6 | 1-amino-2-propanol (1A2P) | |
| 7 | 2-amino-1-butanol (2A1B) | |
| 8 | 2-(methylamino)ethanol (2MAE) | |
| 9 | 2-(ethylamino)ethanol (2EAE) | |
| 10 | 2-(butylamino)ethanol (2BAE) | |
| 11 | 2-(tert-butylamino)ethanol (2TBAE) | |
| 12 | 2-amino-2-(hydroxymethyl)-1,3-propanediol (AHMPD) | |
| 13 | 2-(dimethylamino)ethanol (2DMAE) | |
| 14 | 1-dimethylamino-2-propanol (1DMA2P) | |
| 15 | N,N-diethylethanolamine (DEEA) | |
| 16 | 3-dimethylamino-1-propanol (3DMA1P) | |
| 17 | Isobutylamine (IBA) | |
| 18 | Sec-butylamine (SBA) | |
| 19 | Butylamine (BA) | |
| 20 | N,N,N',N'-Tetramethyl-1,3-propanediamine (TMPAD) | |
| 21 | 3-(dimethylamino)propylamine (3DMAPA) | |
| 22 | 1,3-diaminopropane (DAP) | |
| 23 | Hexamethylenediamine (HMD) | |
| 24 | Diethylamine (DA) | |
| 25 | Triethylamine (TA) | |
| 26 | Hexylamine (HA) | |
| 27 | Triethanolamine (TEA) | |
| 28 | Isopropylamine (IPA) | |
| 29 | Tert-butylamine (TBA) | |
| 30 | Benzylamine (BA) | |

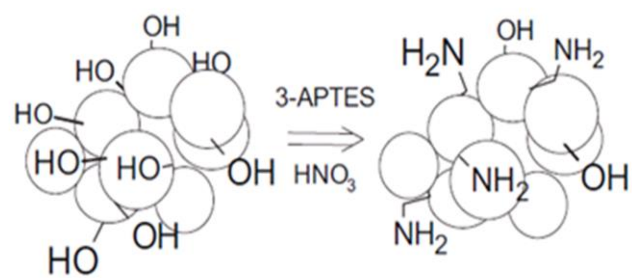


# Bench-scale Development of Advanced Solid Sorbent Material and Suitable Processes for Post-Combustion $CO_2$ Capture

- Optimization and production scale-up of advanced MBS materials in fluidizable form and development of associated fluidized-bed process technology.
- Collection of critical process engineering data using single-stage testing equipment to allow for a detailed design of a bench-scale $CO_2$ capture prototype based on MBS materials.
- Demonstrate technical and economic feasibility of a commercial embodiment of the MBS-based $CO_2$ capture process



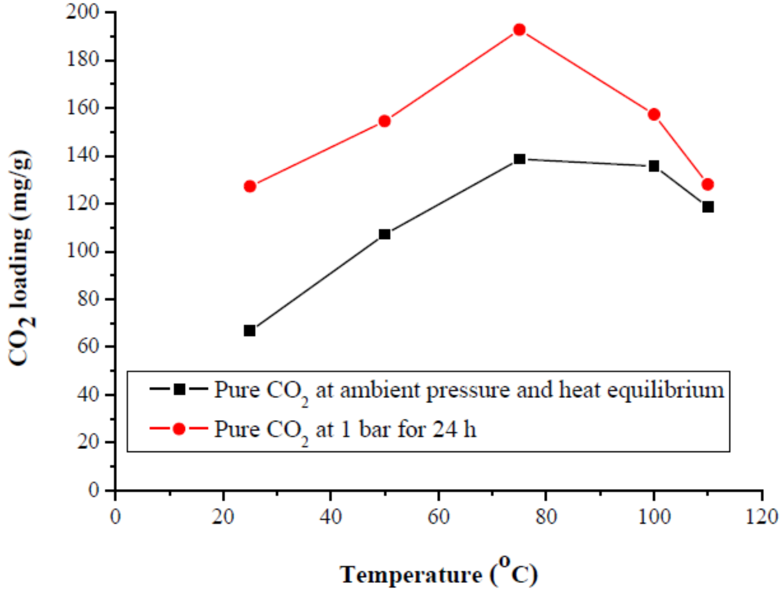

Silica substrates    Solid adsorbent

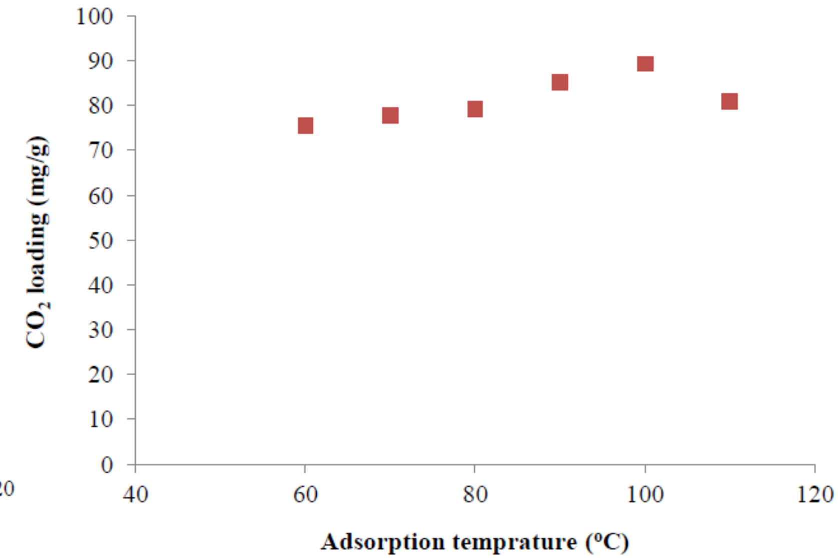


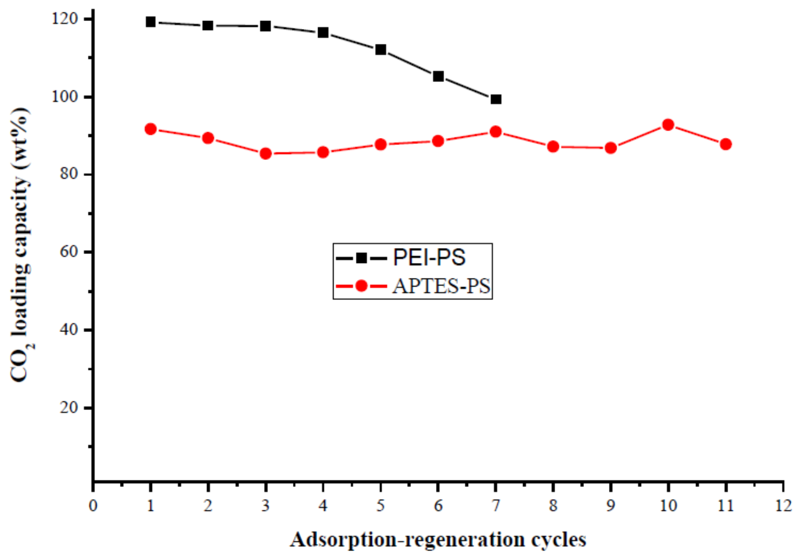

**<u>Faculty at MI</u>**
Dr. Mohammad Abu Zahra

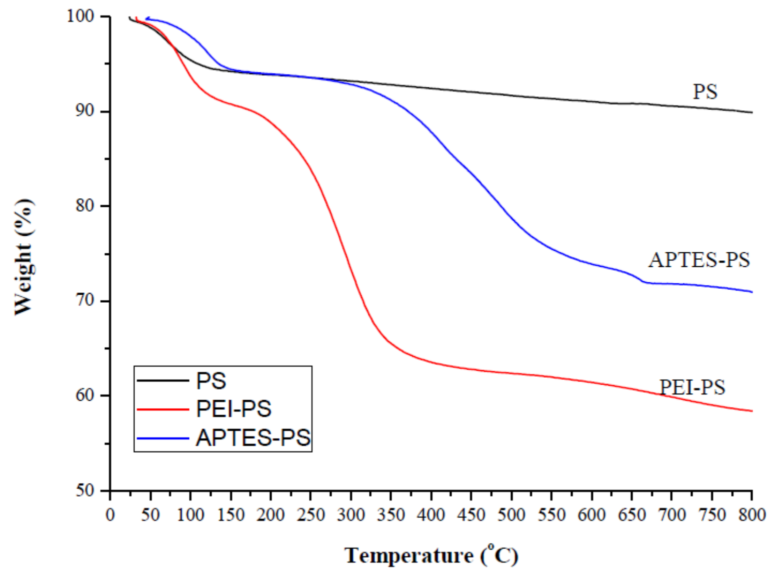
Total project budget: $M 3.4

# Solid Sorbents Performance – Testing at Masdar Institute

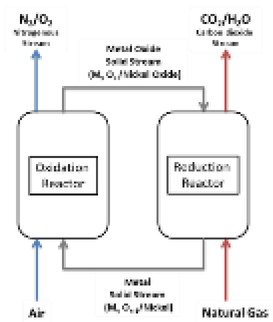


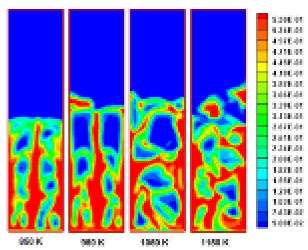



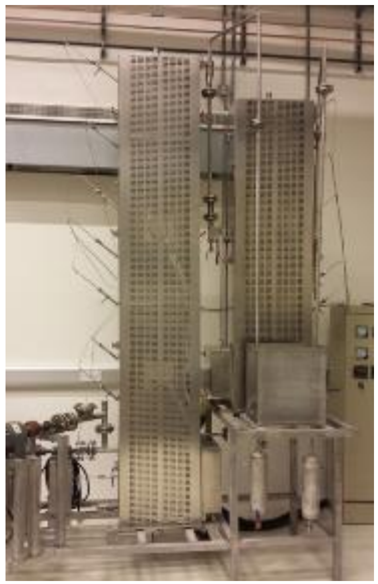



# $CO_2$ Capture by Using Chemical Looping Combustion (CLC)





- **Objective:**

- To develop an innovative $CO_2$ capture process which has minimum energy penalty

- **Approach:**

- To split the combustion of the fuel into two separate reactions carried out in two separate reactors: an oxidation reaction and a reduction reaction, by introducing suitable metal oxide as an oxygen-carrier that circulates between the two reactors

- **Research Issues:**

- Development of a suitable oxygen carrier material
- Efficient design of oxidation and reduction reactors
- Integration of CLC technology with various power cycles

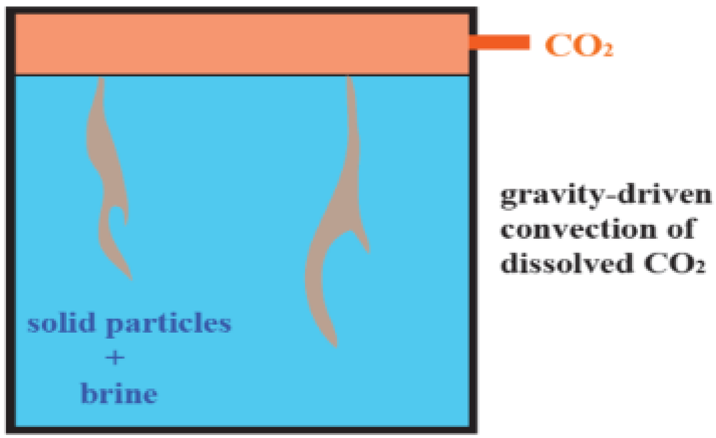
- **Impact:**

- Contribute to the development of efficient $CO_2$ capture technologies

- **Contact:**

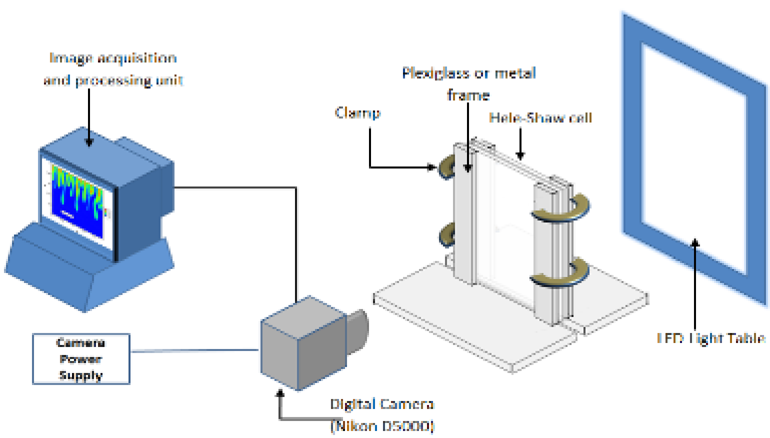
**Dr. Tariq Shamim, Professor of Mechanical Engineering**
**tshamim@masdar.ac.ae**

# Experimental and Numerical Studies of $CO_2$ Injection into Brine-Saturated Rocks: $CO_2$ Dissolution-Diffusion-Convection Process




Hele-Shaw cell

planned size of the inner chamber: 20 cm x 30 cm x 1 mm




- **Objective:**
  - This work studies the dissolution-diffusion-convection phenomena of the buoyant CO2 gasket between the cap rock and the brine saturated formation
- **Approach:**
  - To visualize the phenomena in a Hele-Shaw cell filled with few layers of granular medium saturated with brine.
  - To numerically simulate the phenomena

- **Research Issues**
  - To visualize the different $CO_2$ trapping mechanisms
  - To develop an understanding of the coupled phenomena
  - To correctly simulate the phenomena
- **Impact:**
  - Contribute to the development of efficient $CO_2$ storage technologies
- **Faculty: Prof. Mohamed Sassi, msassi@masdar.ac.ae**

# Other Active UAE Partners

| | |
|---|---|
| ADCO/ ADNOC | • EOR<br>• $CO_2$ Sink |
| Petroleum Institute | • EOR/Storage<br>• Capture: Ionic Liquid, Process intensification |
| UAE University | • Membrane separation<br>• Solid materials |
| Emirate Steal, EMAL, ADWEA, DEWA | • $CO_2$ Source |

## Sponsors

MAERSK OIL

Eng. ESL
Solutions In Engineering Technologies

SIEMENS

Masdar
A MUBADALA COMPANY

## Collaborators:

RTI INTERNATIONAL

CSIRO

MIT Massachusetts Institute of Technology

THE UNIVERSITY OF EDINBURGH

# Thank You

Ver. 1