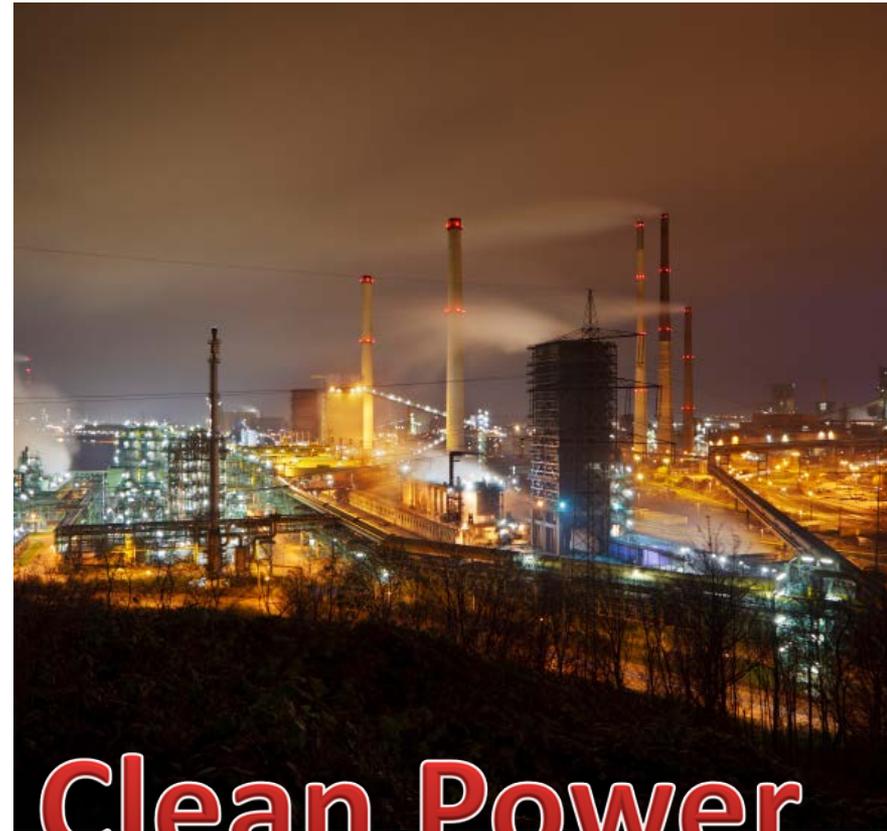


Mixed-salt Technology for CO₂ Capture from Power Plants

Indira Jayaweera
Sr. Staff Scientist and CO₂ program Leader
Energy and Environment Center
SRI International

Presented at CO₂ Capture Technology Workshop
California Energy Commission, Sacramento
April 16, 2015



Clean Power

Agenda

Introduction

Mixed-Salt Technology

Current Development and Test Results

Technology Comparison and Potential
for Improvements

SRI International

- An independent, nonprofit corporation
- Annual R&D Projects: ~ \$500 million
- More than 2,100 employees (> 600 PhD's)
- 21 locations worldwide
- Headquarters located in Menlo Park, CA

Silicon Valley - Headquarters



Washington, D.C.



Princeton, New Jersey



Harrisonburg, Virginia



St. Petersburg, Florida



State College, Pennsylvania



Arecibo, Puerto Rico



Tokyo, Japan



SRI: Engaged in Carbon Capture Research Since 2004

Sorbent, Solvent, and Membrane Separation Approaches

Post-combustion



Chilled Ammonia Mini-pilot



Falling Bead Reactor



Mixed Salt Process

Pre-combustion



AC-ABC Process

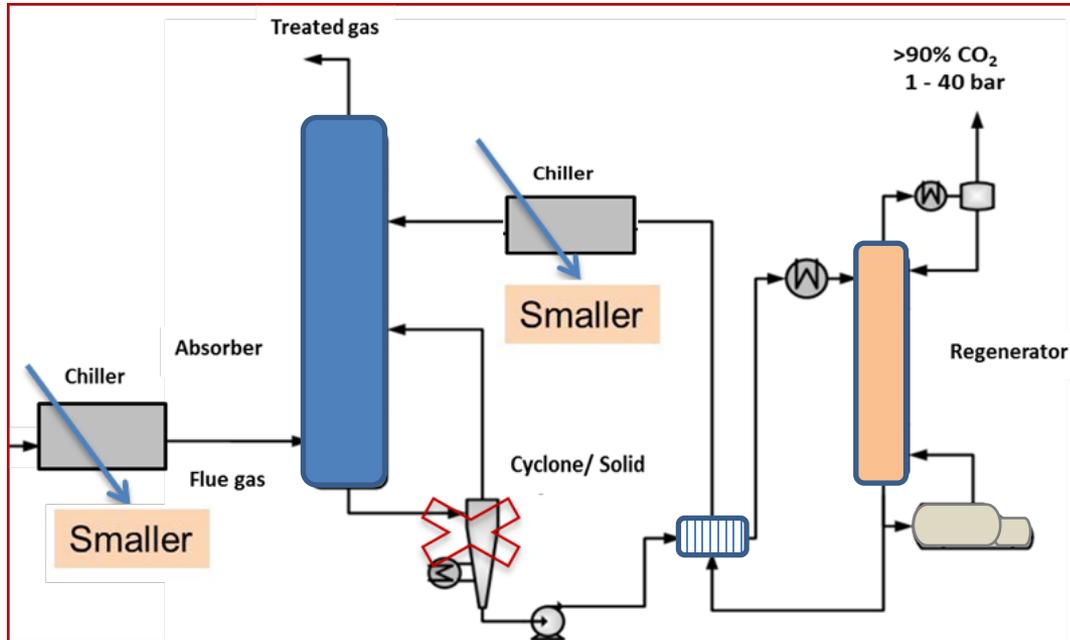


High Temperature PBI Membrane Skid

Air Capture



Current Carbon Capture Technologies are Energy- and Water-Intensive

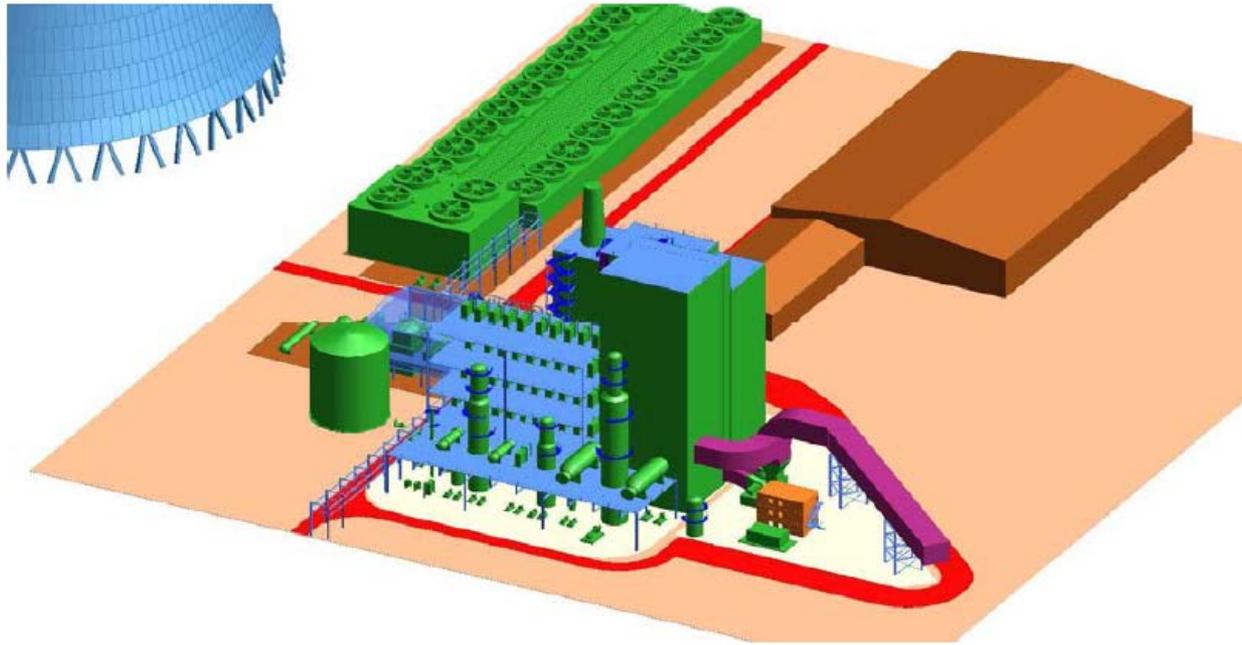


Currently available alternatives to amine technology include ammonia, potassium carbonate

Need to reduce high energy penalties related to:

- Solvent chilling
- Solid dissolution (heat requirement for salt dissolution can be up to 1MJ/ kg CO₂)
- Water use for ammonia emission control
- Sour water stripper

Mixed Salt Offers Advantages over the Chilled Ammonia Process (CAP)



250 MWe, Turceni, Romania CO₂ Capture Plant View (2012 feasibility study report)

SRI Mixed-salt process will have

- a smaller footprint
- reduced water use compared to CAP

Mixed-Salt Process Details: Absorber, Regenerator Operating Conditions and Overall Benefits



Key Benefits:

- Reduced ammonia emissions
- Enhanced efficiency
- Reduced reboiler duty
- Reduced CO₂ compression energy

A SIGNIFICANT PARASITIC POWER REDUCTION COMPARED TO MEA !

How it Works:

Selected composition of potassium carbonate and ammonium salts

- Overall heat of reaction 35 to 60 kJ/mol (tunable)

Absorber operation at 20 - 40° C at 1 atm with 35-40 wt.% mixture of salts

Regenerator operation at 70 - 180° C at 10-20 atm

- Produce high-pressure CO₂ stream

High CO₂ cycling capacity (~ 15-20 wt%)

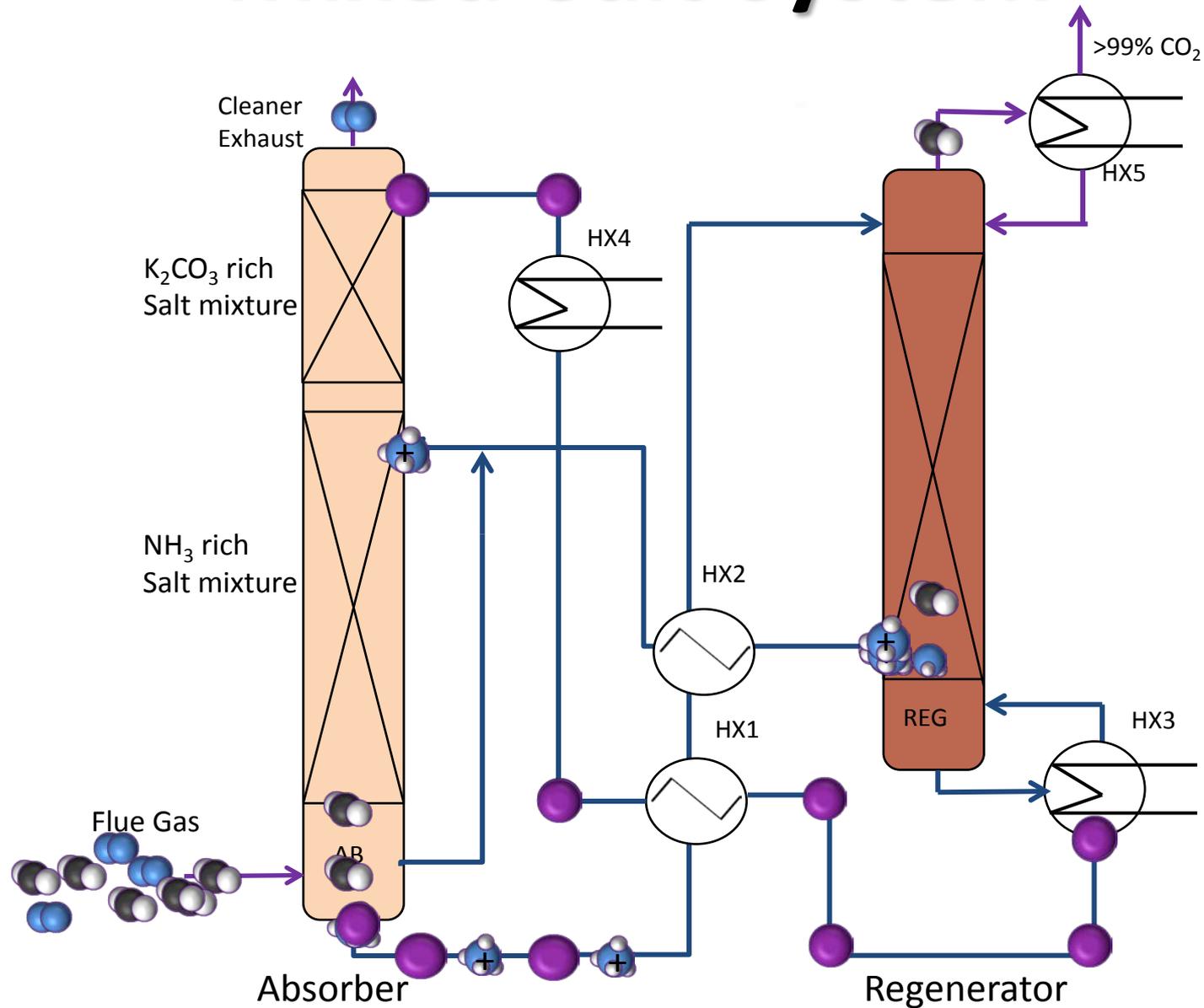
No Solids

CO₂ Lean

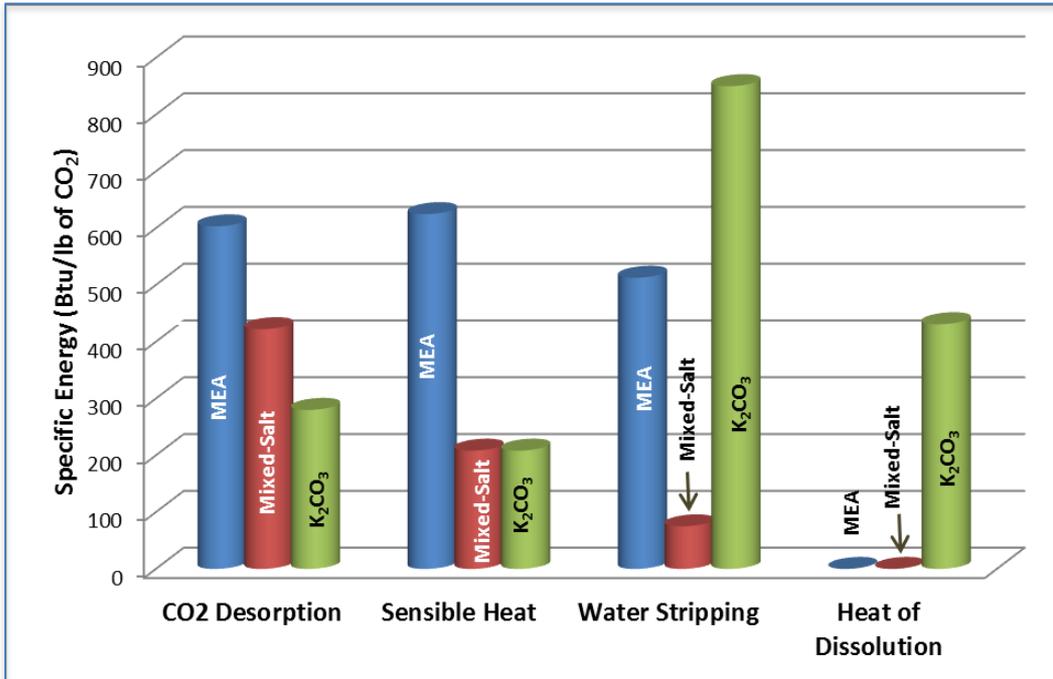
CO₂ Rich



Mixed-Salt System

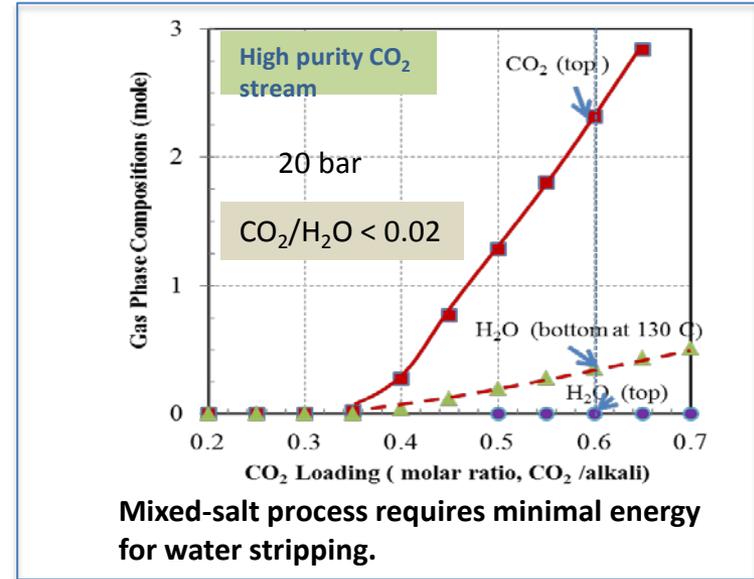


Mixed-Salt has a Low Energy Requirement for CO₂ Stripping

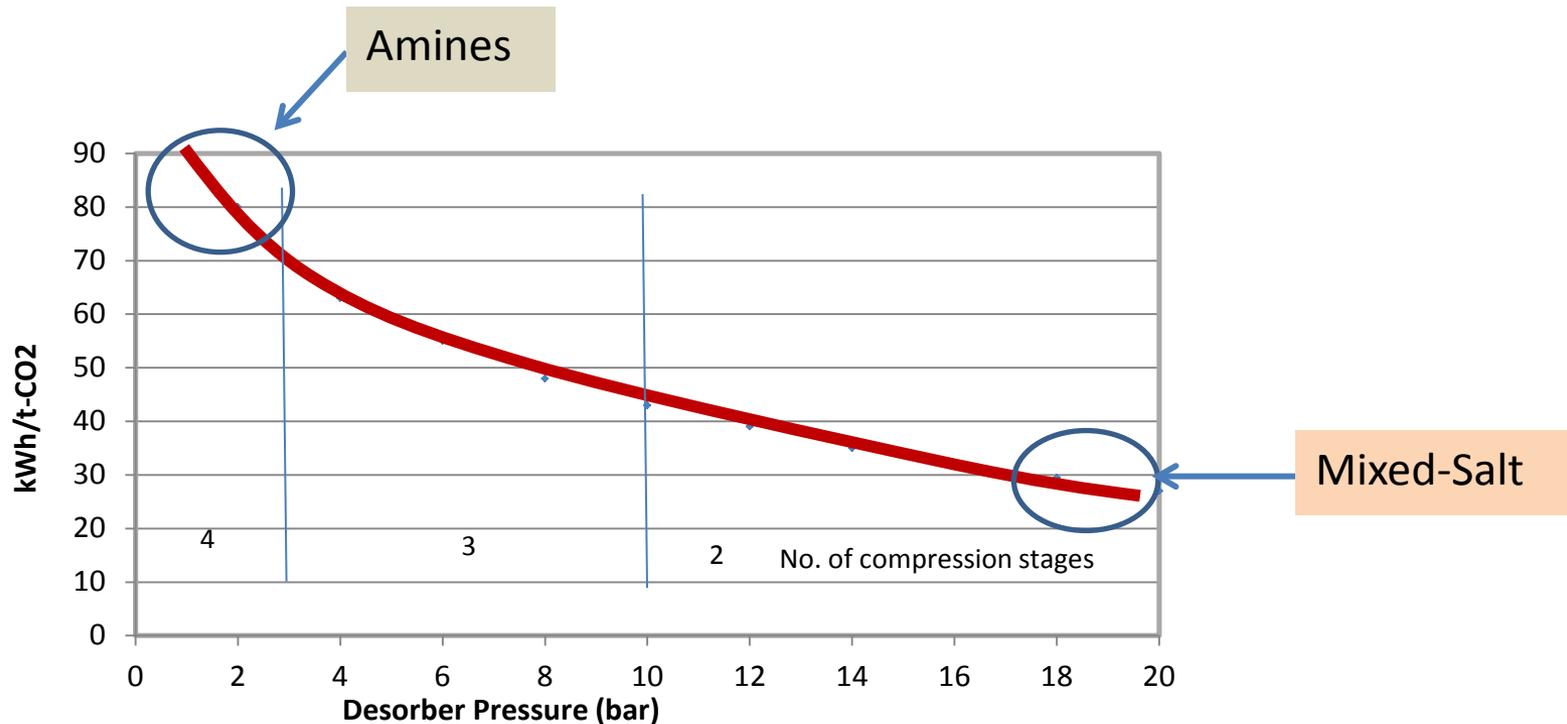


Estimated regenerator heat requirement for mixed-salt system with 0.2 to 0.5 cyclic CO₂ loading. Comparison with neat K₂CO₃ and MEA is shown.

Sources: MEA Data: CSIRO Report (2012). EP116217
 K₂CO₃ Data: GHGT-11; Schoon and Van Straelen (2011). TCCS-6
 Mixed-Salt Data; SRI Modeling



Mixed-Salt Requires Less Energy for CO₂ Compression



Electricity output penalty of compression to 100 bar as a function of desorber pressure

Source: Luquiaud and Gibbins., Chem Eng Res Des (2011)

Current Project Development

Project Time Line

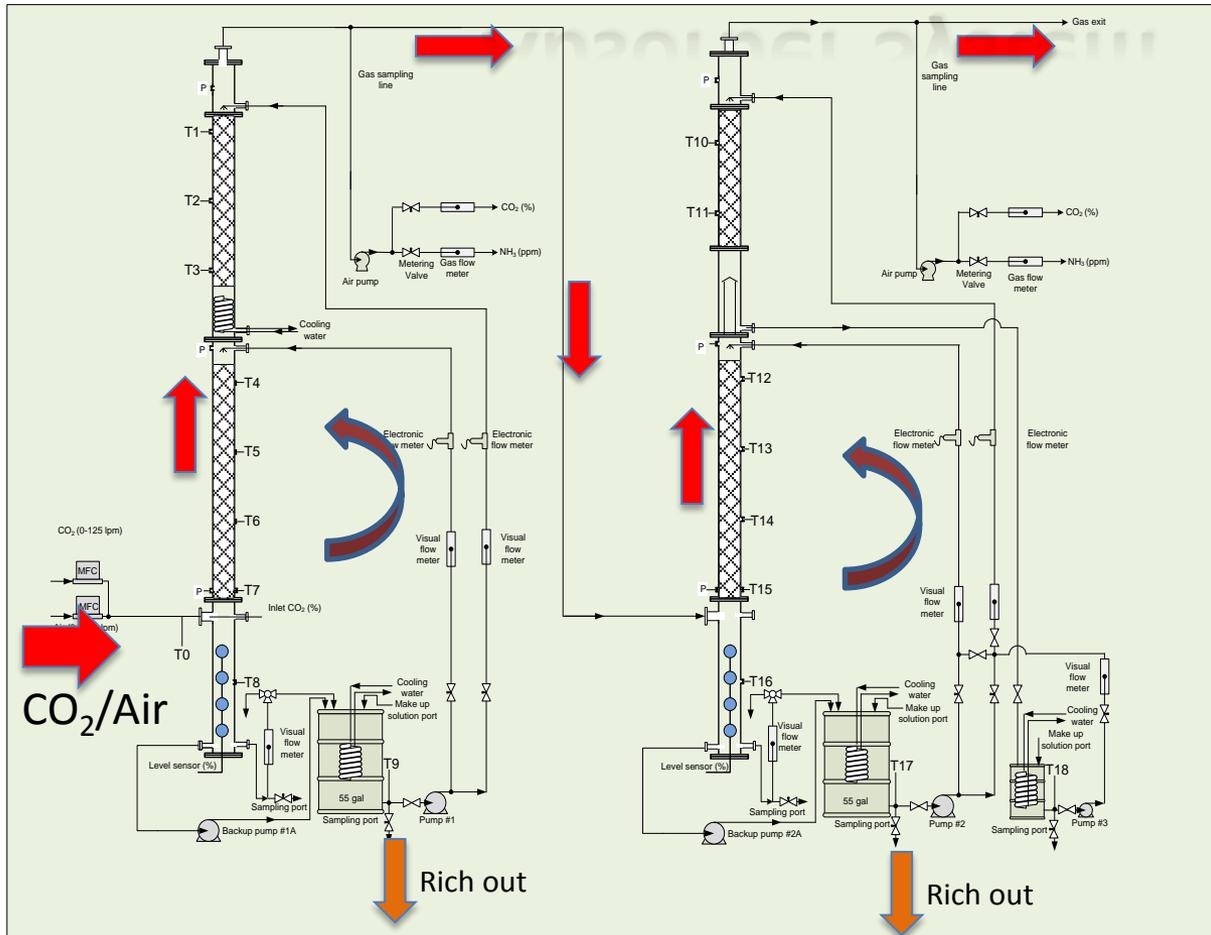
SRI Funded Project (2012): Proof of Concept- lab scale work and thermodynamic modeling

Commercially Funded Project (2013-on going): Demonstrate that the process regeneration energy requirement is $< 2 \text{ MJ/kg-CO}_2$

DOE Funded Project (2013-2016): **FE0012959**

- Demonstrate the system operation with $> 90\%$ CO_2 capture, high CO_2 cyclic loading (0.2 to 0.5 CO_2 mol/ mol of alkaline) with reduced ammonia emissions
- Prepare Techno Economic Analysis (TEA) and Environmental Health and Safety reports for the process

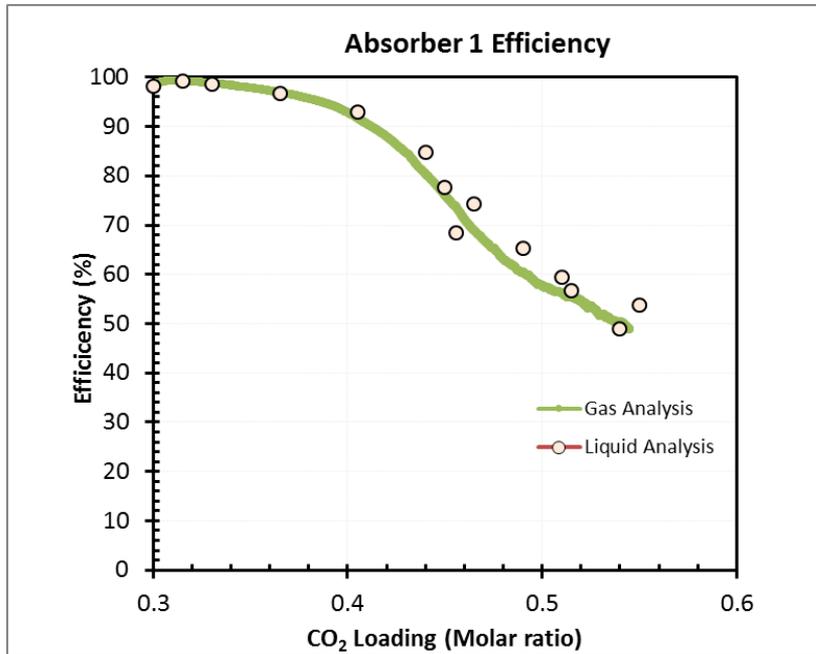
Schematic and Photograph of the Absorber System



0.3 to 1 t-CO₂/day capacity

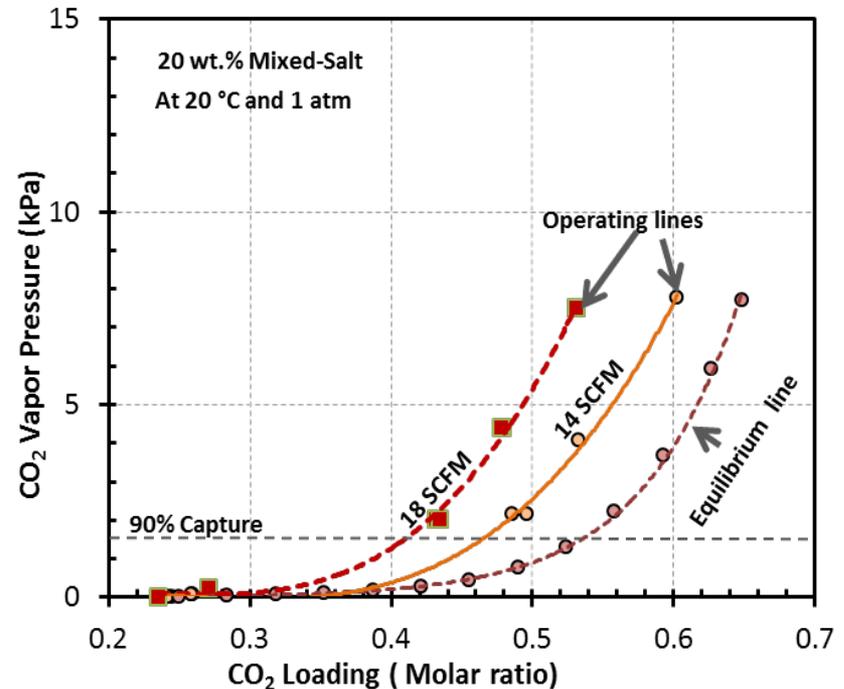
Bench-Scale Absorber Performance

Test Data



Better than 90% efficiency with incoming lean absorption solution with < 0.4 CO₂ loading

Modeling and Test Data

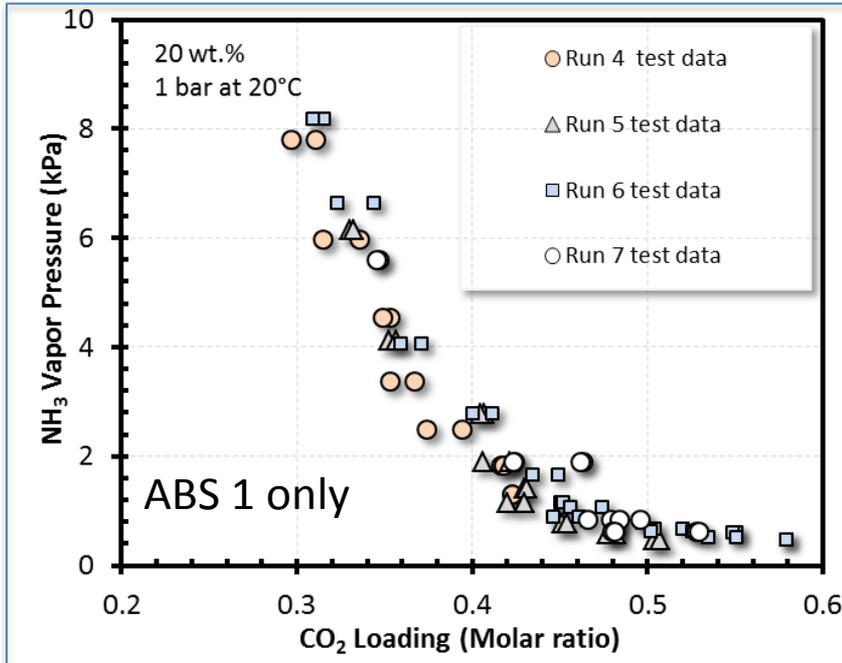


CO₂ vapor pressure at the absorber exit under various CO₂-loading conditions

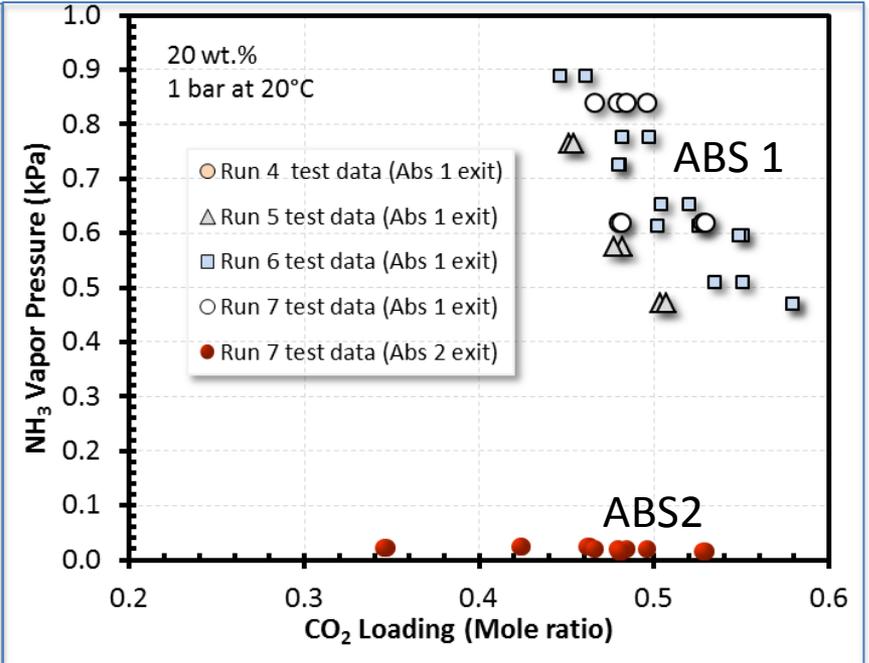
The observed overall rates for CO₂ absorption are on the same order as those of MEA-based systems and about 5-7x higher than chilled ammonia systems

Process Ammonia Management

Test Data

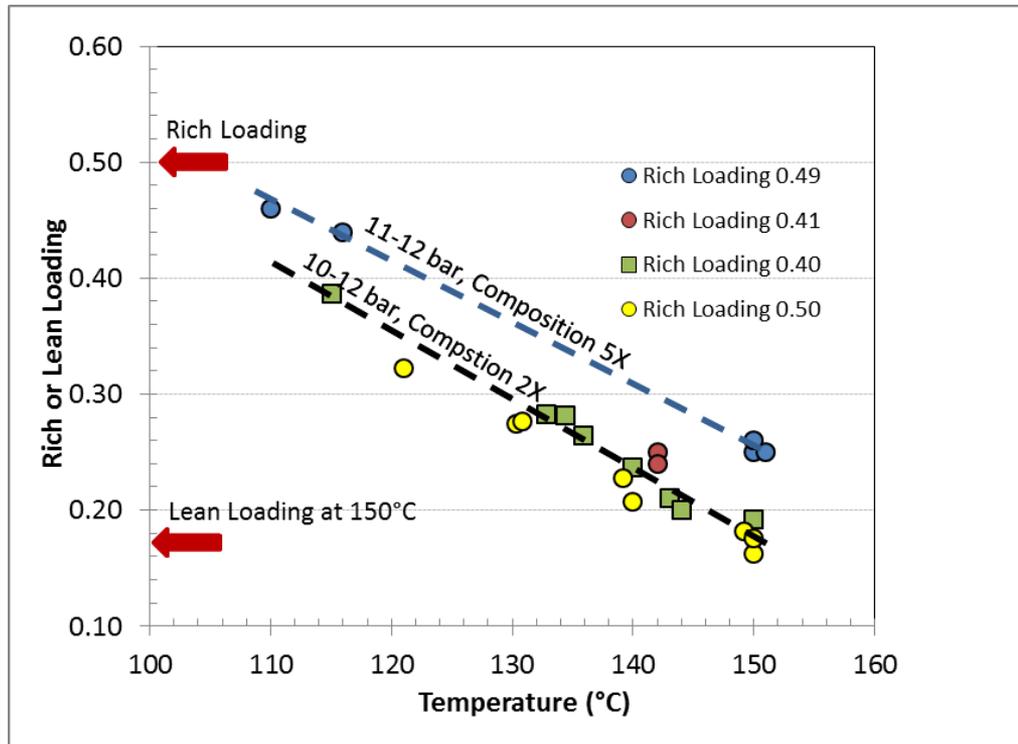


NH₃ vapor pressure at the Absorber 1 exit under various CO₂-loading conditions.



NH₃ vapor pressure at the Absorber 1 and 2 exits under various CO₂-loading conditions.

Regenerator Performance Test Data

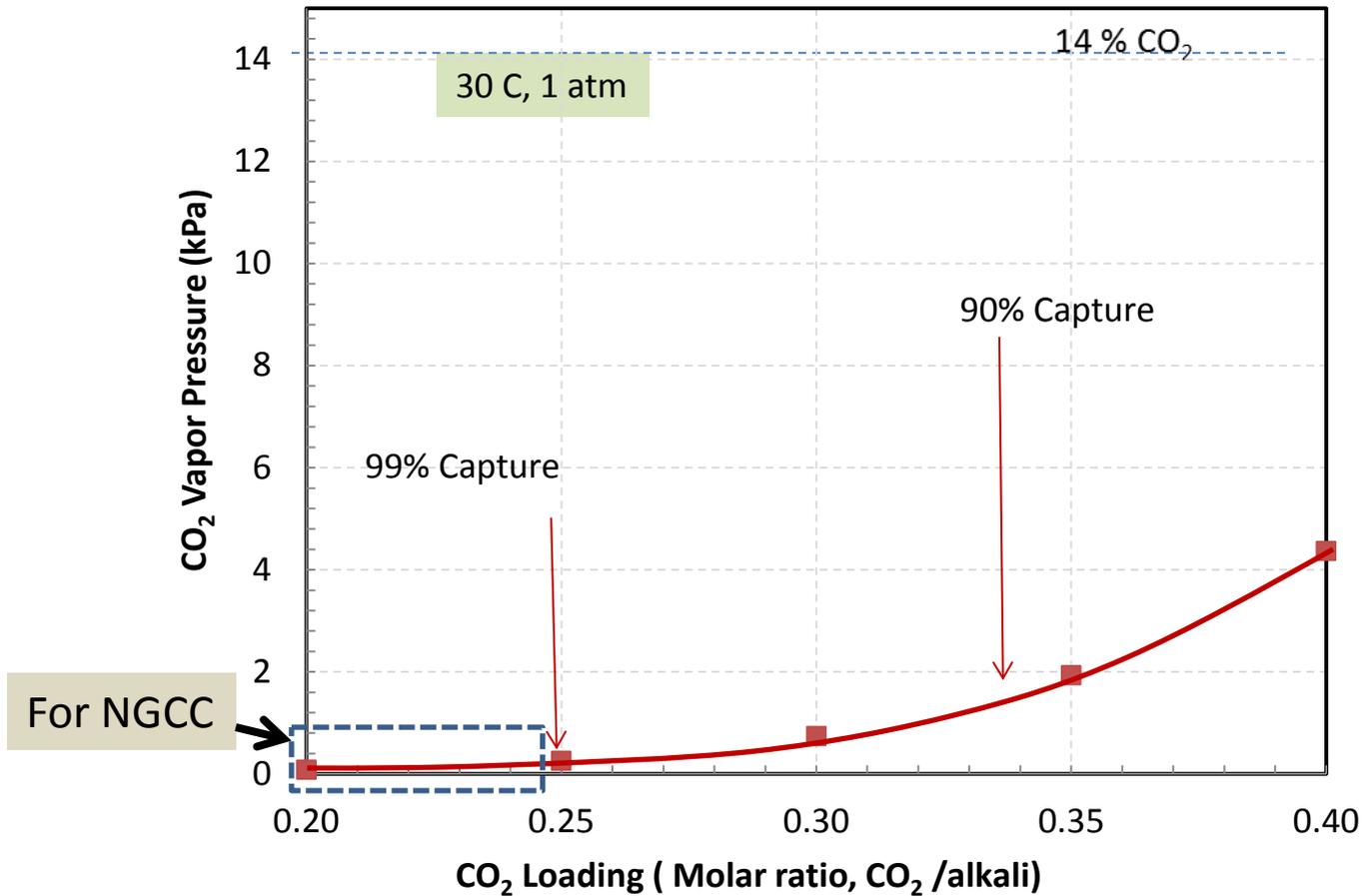


Process was demonstrated with cyclic loading from 0.2 to (lean) to 0.5 (rich) at 150° C

Variation of attainable CO₂-lean loading level with temperature for rich loadings of 0.40 to 0.50 at 10-12 bar

The produced lean loading well exceeds that required for >90% CO₂ capture from flue gas streams containing 3-15 vol% CO₂

Absorber Equilibrium Modeling Case: 38 wt% Total Mixed Salt



Mixed salt can capture > 90% CO₂

Mixed-Salt Performs Well on Key Process Parameters



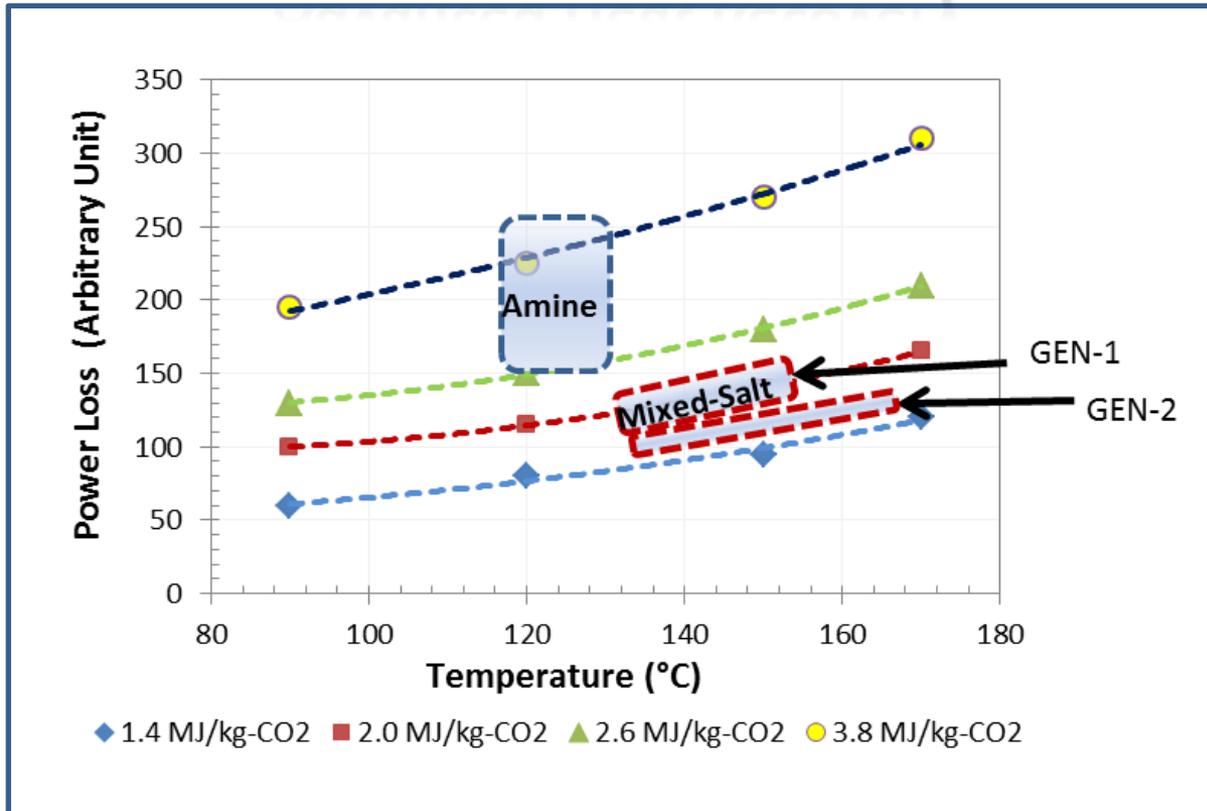
Solvent or Process	SO _x and NO _x Handling	Oxidation Inhibitor	Solvent Make-up	Compression Ratio	Specific Heat Requirement GJ/tonne CO ₂
MEA	<10 ppm	Required	2 kg/ tonne CO ₂	150	3.9 - 4.2
KS-1	< 1 ppm	Required	0.35 kg/ tonne CO ₂	150	2.9
K ₂ CO ₃	Light FGD	Not required	<0.1 kg/ tonne CO ₂	>100	3.0 - 4.0
Aqueous Ammonia	Light FGD	Not required	Ammonia loss	>100	<2.9
Chilled Ammonia	Light FGD	Not required	0.2 kg/ tonne CO ₂	<5	<2.9
Mixed-Salt	Light FGD	Not required	<0.1 kg/ tonne CO ₂	<5	<2.0

Sources: Yi and Kim, 2008: PCC S&T seminar at CSIRO; IPCC Special Report on Carbon Dioxide Capture and Storage

Chemical cost

Waste disposal cost

Next Generation Mixed Salt Technology Will Include Advanced Heat Recovery



The net loss in power output from the steam cycle due to steam extraction for capture as a function of solvent regeneration temperature and solvent heat requirement for regeneration.

Source: Data extracted from Gibbins, 2011

GEN-1: Current Project

GEN-2: Advanced Heat Recovery (seeking funding)

Mixed-Salt Technology Summary



– Process Summary

- Uses inexpensive, industrially available material (potassium and ammonium salts)
- Requires no feed stream polishing
- Does not generate hazardous waste
- Has the potential for easy permitting in many localities
- Uses known process engineering

- Demonstrated Benefits:

- Enhanced CO₂ capture efficiency
- High CO₂-loading capacity
- High-pressure release of CO₂

Acceptable For NGCC Application:

- Oxygen tolerant solvent
- Applicable to low CO₂ concentrations

- Expected Benefits:

- Reduced energy consumption compared to MEA
- Reduced auxiliary electricity loads (e.g., solvent chilling) compared to the chilled ammonia process
- Possible flexible carbon capture operation



Scale-up Plan of Mixed-Salt Process for CO₂ Capture from Coal Power Plants

Bench-Scale System of SRI

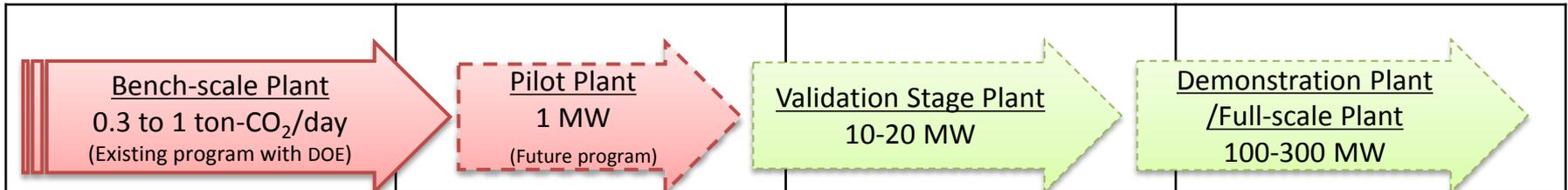
2013

2015

2020

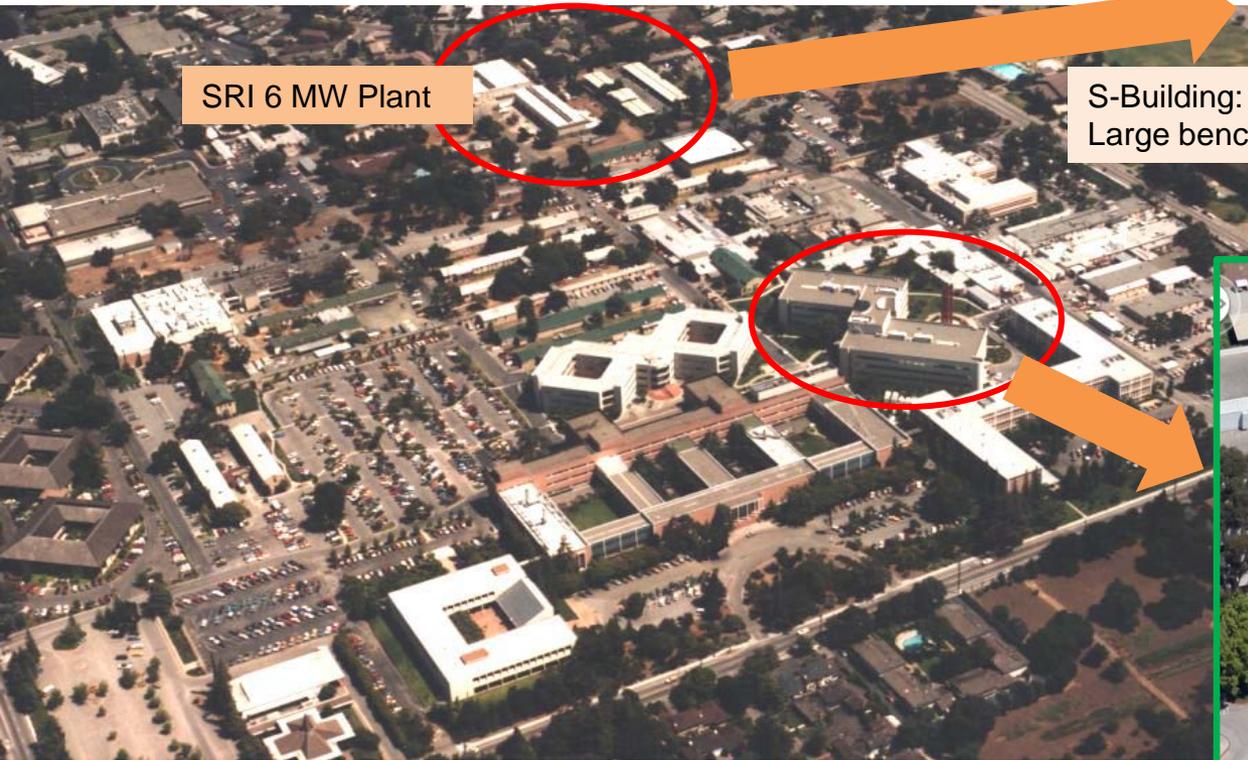
2025

2030



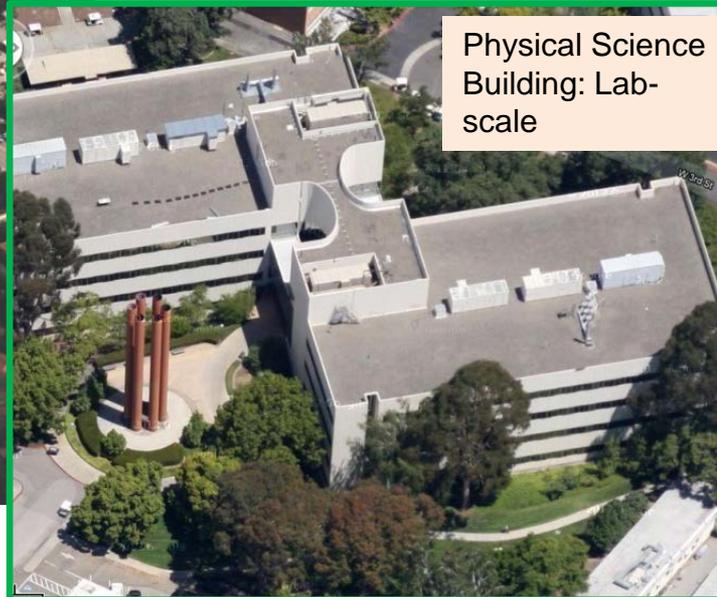
SRI is Demonstrating Carbon Capture Technologies

On site utilities:
Power, Water, Air, Steam



SRI 6 MW Plant

S-Building:
Large bench and mini-pilot



Physical Science
Building: Lab-
scale

*SRI's site in Menlo Park, CA (~ 65 acres)
SRI also has a test site near Livermore, CA (480 acres)*

Acknowledgement and Disclaimer

- This presentation includes material based upon work supported by the Department of Energy, National Energy Technology Laboratory, under award number DE-FE0012959
- This presentation includes an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.