


Engineering-Scale Demonstration of the Mixed-Salt Process (MSP) for CO_2 Capture

DOE Contract: DE-FE0031588

Presented by: Indira Jayaweera, Sr. Staff Scientist and Sr. Program Manager

SRI International

333 Ravenswood Ave.

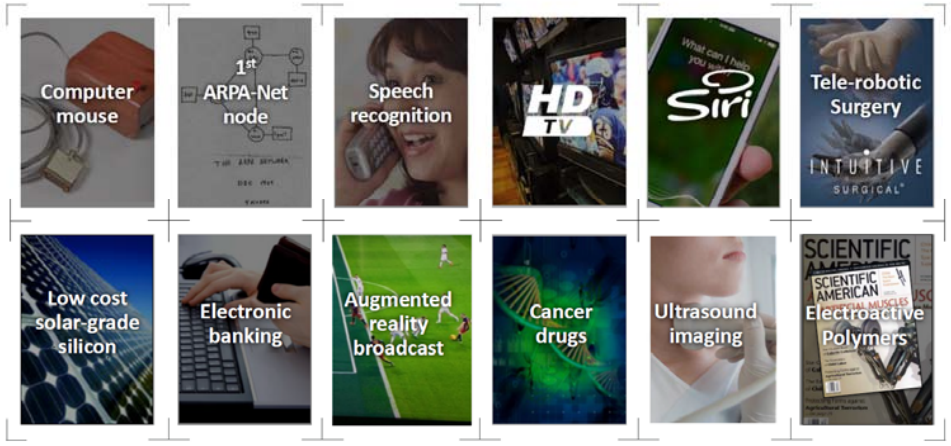
Menlo Park CA 94025

Carbon Management Technology Conference (CMTC), Houston - July 17, 2019

- SRI is an independent, leading nonprofit research organization
  - Founded by Stanford University in 1946
  - Annual R&D Projects: ~ $500 million
- Mission : To change the world by making people safer, healthier, and more productive!

SRI International

SRI's world-changing innovations...



SRI Ventures

SRI Ventures is the commercialization arm of SRI International. We have created and launched more than 70 ventures with a total market capitalization of over $20 billion. Over 33% of our companies have had successful exits.

In 2017, we launched 7 startups and they raised over $60 million.

In 2018, we launched 7 successfully-funded startups

Portfolio Companies

abundant ROBOTICS · a16z · Artificial Muscle · Averatek · DESTI · Intuitive Surgical · Nuance · KASIST · kuato studios · LEO Labs · Siri · Princeton Lightwave · REDCOAT Solutions · redwood robotics · re scan · SUPERFLEX · TaaSera · tempo · TOUT · Meta

Disclaimer

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.

Project Background and Technology

2016 SRI International

Project Objectives

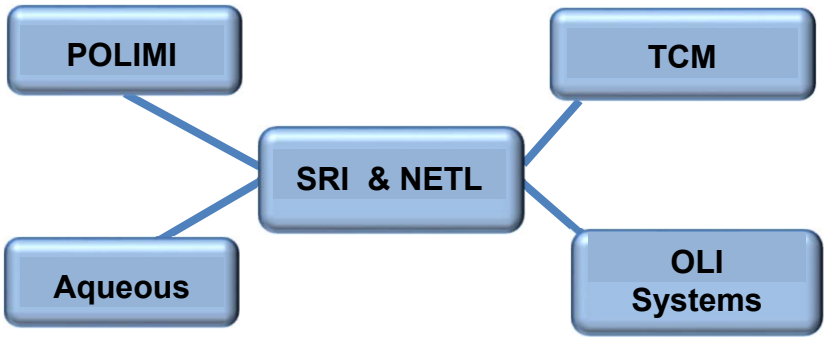
(DOE Contract: FE0031588)

- Perform integrated MSP testing at engineering scale for long-term periods under dynamic and continuous steady-state conditions with a real flue gas stream to address concerns relating to scale-up and integration of the technology to coal-based power plants;
- Operate the MSP with advanced heat integration to improve the process efficiencies;
- Study the solvent and water management strategies; and
- Collect critically important data for a detailed techno-economic analysis (TEA) and for further process advancements to reach the DOE's goal of \$30/tonne of CO_2 by 2030.

Key Focus:
(1) Process optimization, energy efficiency, chemical consumption and low emissions
(2) Dynamic and steady-state operations

Project Team

DOE Project Manager: Andrew Jones
Prime Contractor: SRI International
Project Team: US and International Partners
Project Value: ~ $22 M
(DOE funding and TCM in-kind cost-share)



- TASK 1.0 (BP1,BP2 & BP3) - Project Management and Execution
- Task 2 (BP1) – Detailed investigation of required changes to the TCM CAP Plant to run MSP
- TASK 3.0 (BP2) - Re-commissioning of the CAP Pilot at TCM
- TASK 4.0 (BP2) - System Modification, Modeling and Initial Testing
- TASK 5.0 (BP3) - Dynamic and Steady-state Testing of MSP
- TASK 6.0 (BP3) - Process Economics, Technology Gaps and Technology Maturation
- TASK 7.0 (BP3) - Environmental, Health and Safety (EH&S) Assessment
- TASK 8.0 (BP3) – Pilot plant shutdown and Project Closure

Work Organization

SRI International
Technology provider

Technology Center Mongstad (TCM), Norway
Host site and cost-share partner

OLI Systems, USA
Process modeling

Aqueous Systems Aps, Denmark
Thermodynamic modeling

POLIMI, Italy
Techno-economic analysis

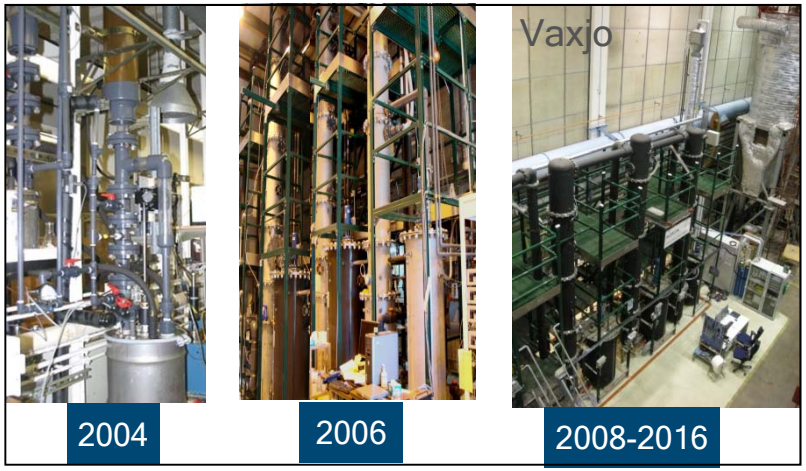
© 2015 SRI International

MSP Developments

Small bench to mini-pilot to large pilot

Ammonia technology development started at SRI in 2004

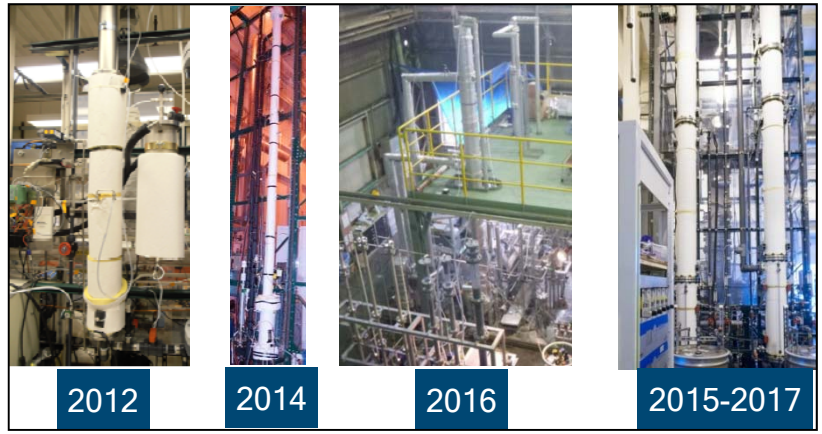
Chilled Ammonia Process (CAP)



CAP Validation at TCM

Step change

Mixed-Salt Process (MSP)



MSP Testing at TCM
DE-FE0031588

Mixed-Salt Process (MSP)

How it works:

Selected composition of potassium carbonate and ammonium salts

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

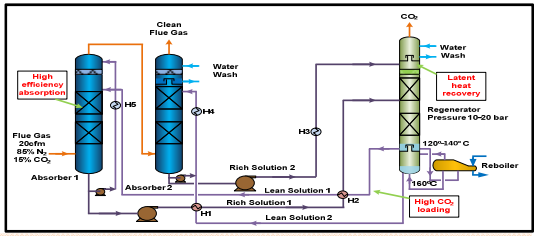
Absorber operation at 20° - 40° C at 1 atm with 30-40 wt.% mixture of salts

Regenerator operation at 120° - 160° C at 10-20 atm

- Produce high-pressure CO_2 stream

K_2CO_3–NH_3–CO_2–H_2O system

High CO_2 cycling capacity



Process Highlights:

- Reduced ammonia emissions
- Enhanced efficiency
- Reduced reboiler duty
- Reduced CO_2 compression energy

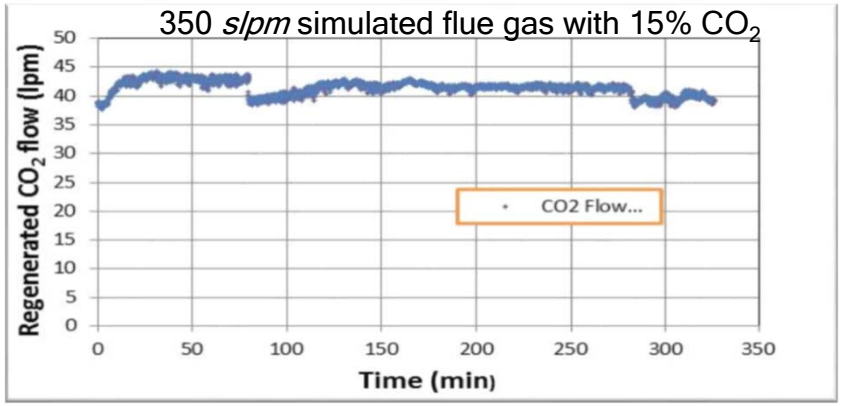
A SIGNIFICANT PARASITIC POWER REDUCTION COMPARED TO MEA !

MSP Mini-pilot at SRI

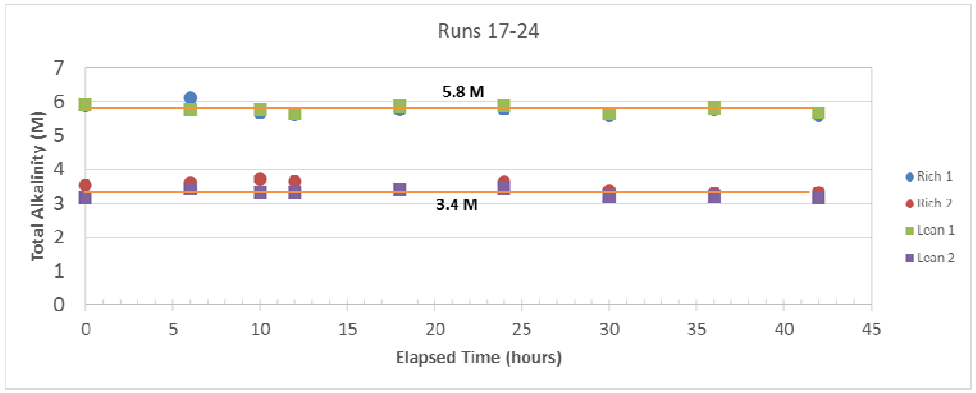
©2017 SRI International

Examples of Steady-State and Dynamic Testing of the Large Bench (mini-pilot)

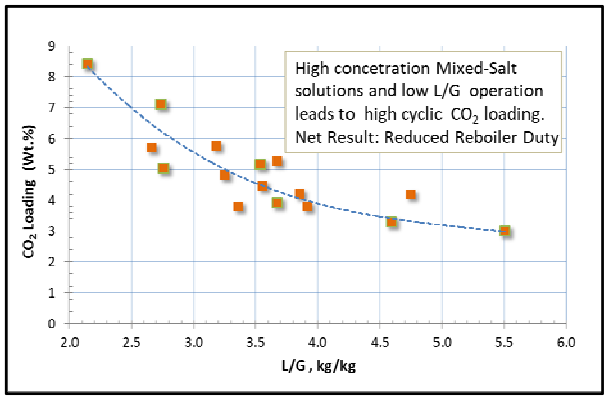
Results from FE0012959



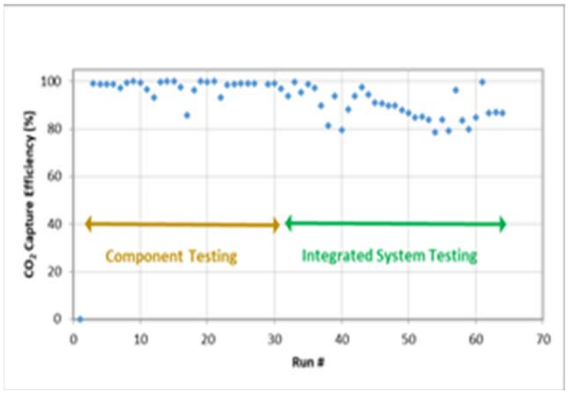
Observed 90% capture efficiency and regeneration with cyclic loading of ~0.7 mole of CO_2/mole of ammonia



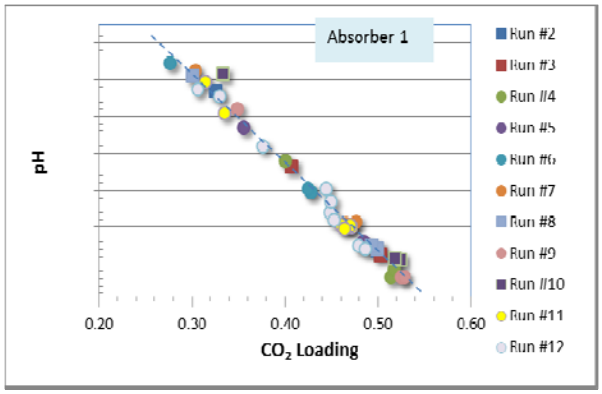
Alkalinity of rich and lean solutions circulating in the integrated system



Observed CO_2 loading as a function of L/G



CO_2 capture efficiency in parametric test runs



Observed pH as a function of CO_2 loading

Absorber: 20-35°C; Regenerator : 140°C; Reboiler: 160°C;L/G = 2 to 6 (kg/kg); Solvent composition: 5 to 8 m

MSP Summary and Benefits

Process Summary

- Uses inexpensive, industrially available material (potassium and ammonium salts)
- No chemical degradation
- Has the potential for easy permitting in many localities
- Uses known process engineering
- Accelerated development possible

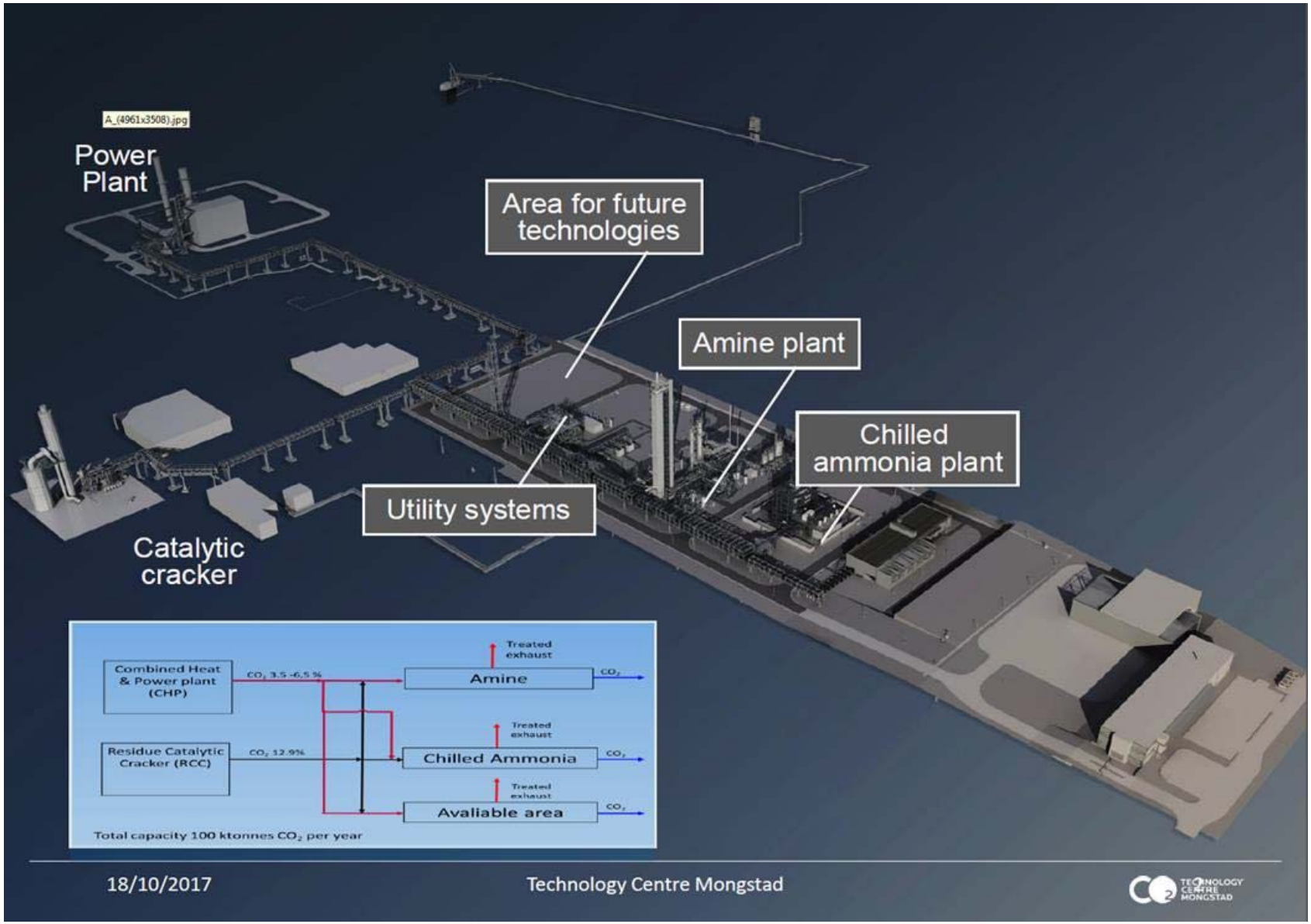
Demonstrated Benefits (By testing and/or modeling)

- Enhanced CO_2 capture efficiency
- High CO_2-loading capacity
- High-pressure release of CO_2 (10-20 bar)
- Reduced energy consumption (~ 2 MJ/kg-CO_2)
- Reduced auxiliary electricity loads

Project Start and Site Preparation

2017 SRI International

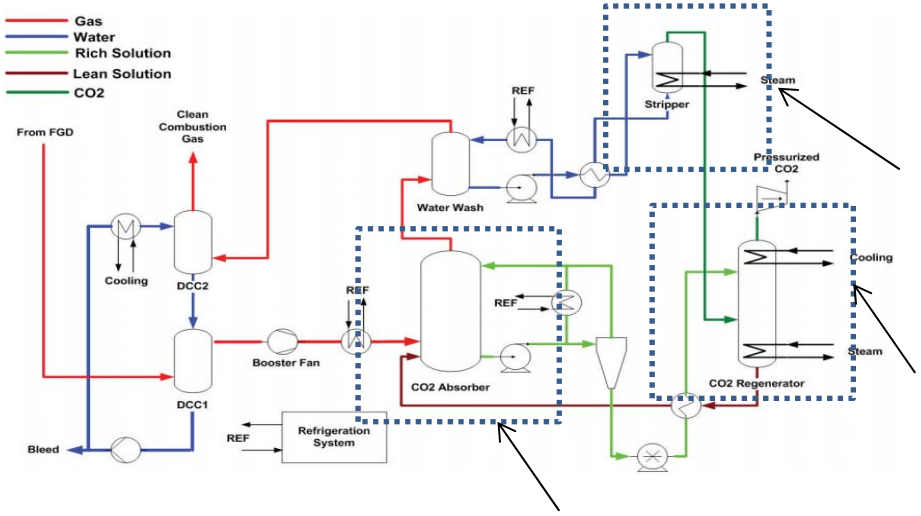
Plant View of TCM



CAP Plant at Technology Center Mongstad (TCM)

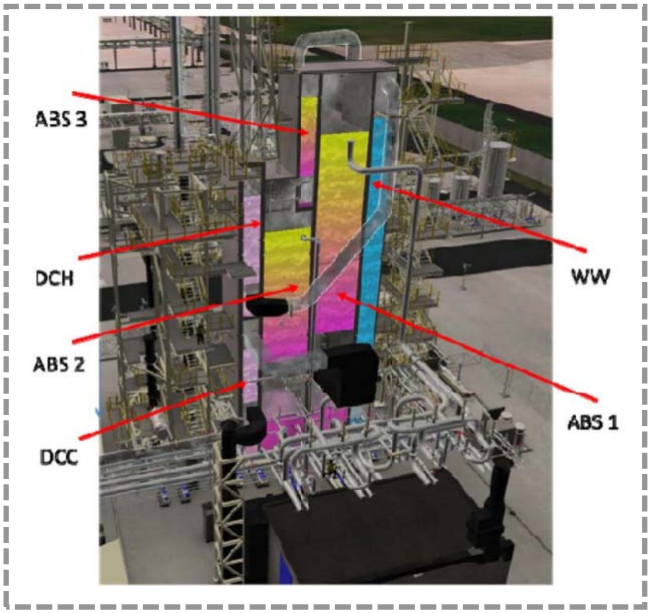
Source: https://www.norskpetroleum.no/wp-content/uploads/TCM_Mongstad_foto_Helge_Hansen_Statoil_1440_480-1440x480-c-default.jpg

Existing CAP Infrastructure at TCM



Process flow diagram of the as-built CAP system

Source: Energy Procedia 114 (2017) 5593 – 5615



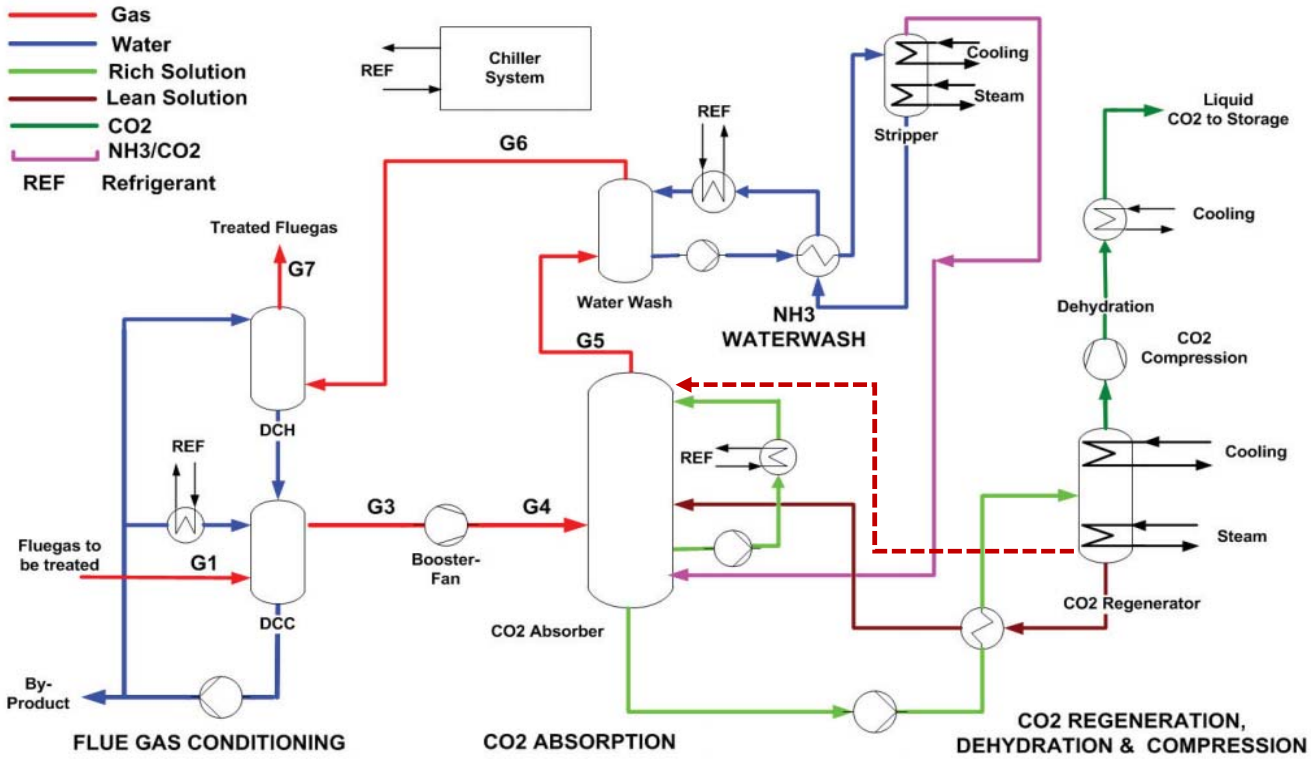
Absorber Block

Regenerator and Ammonia Recovery Blocks

Source: Energy Procedia 51 (2014) 31 – 39

CAP System Modification

MSP testing will be in non-solid mode



New Piping to Demonstrate MSP

Non Solid Mode Operation Flow Scheme

Key Modifications:

Absorber rearrangement (piping, valves etc.)

New lean transfer line from regenerator to absorber (piping, valves etc.)

Project Timeline

For system recommission, modification and testing

Completed or Ongoing Activities:

Contract Negotiation Phase 1 ✓

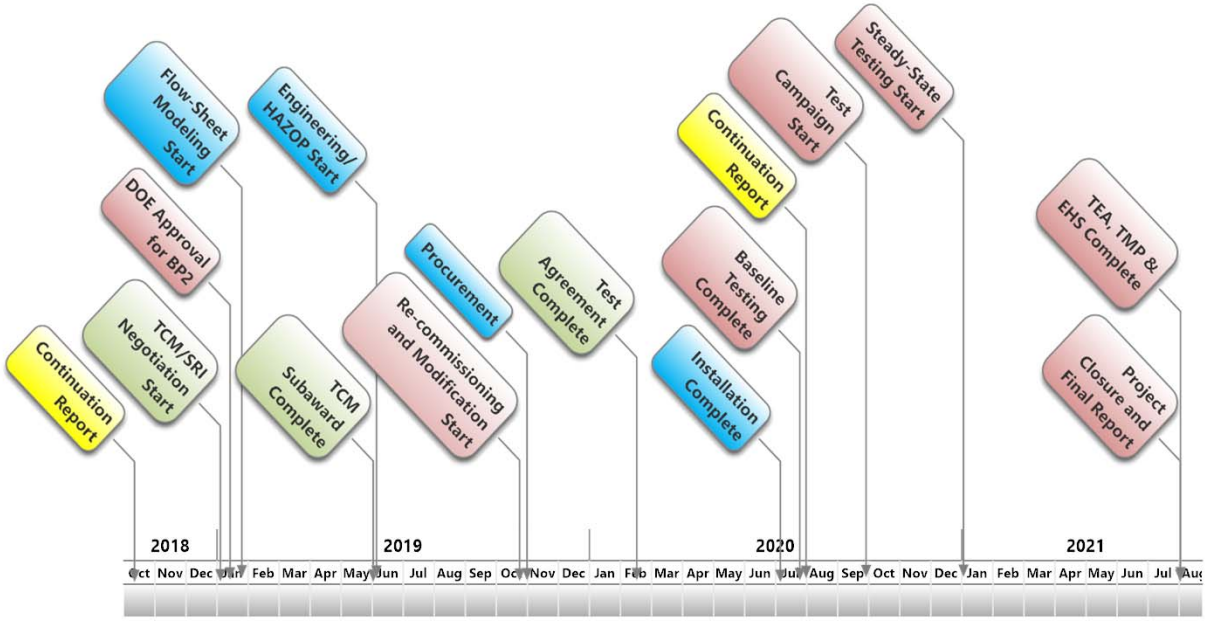
Prep work for recommission – system investigation ✓

Contract Negotiation Phase 2 ✓

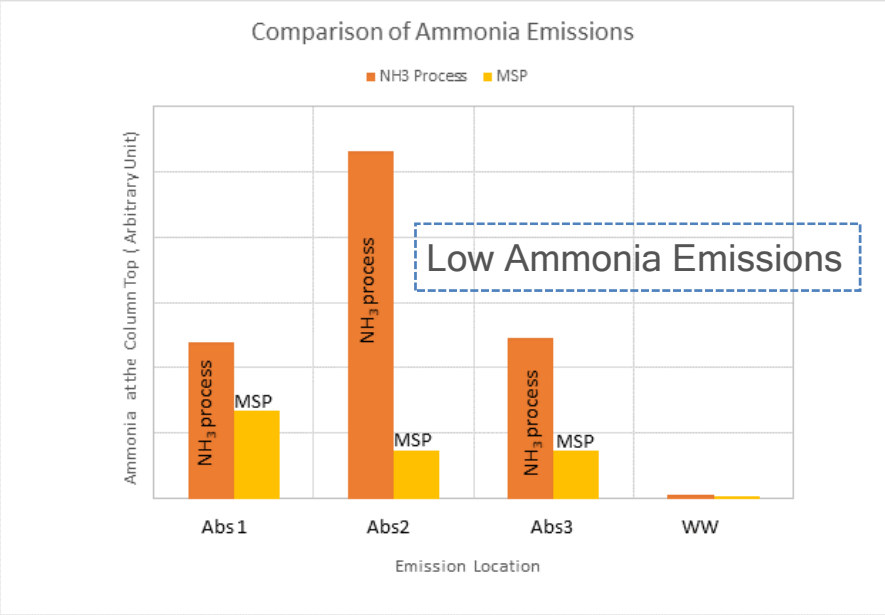
Prep Work and Engineering for Modification (in progress)

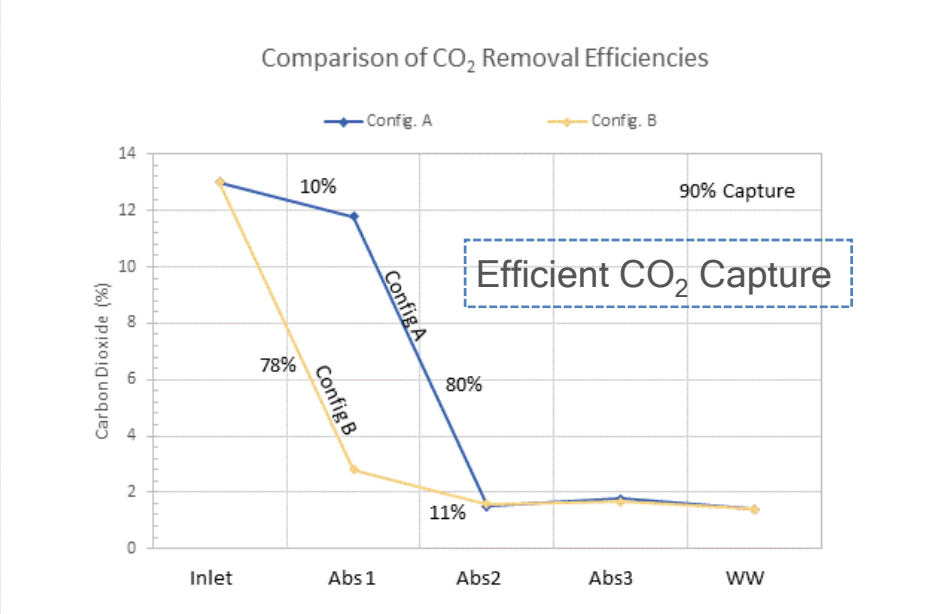
Flow-sheet modeling ✓

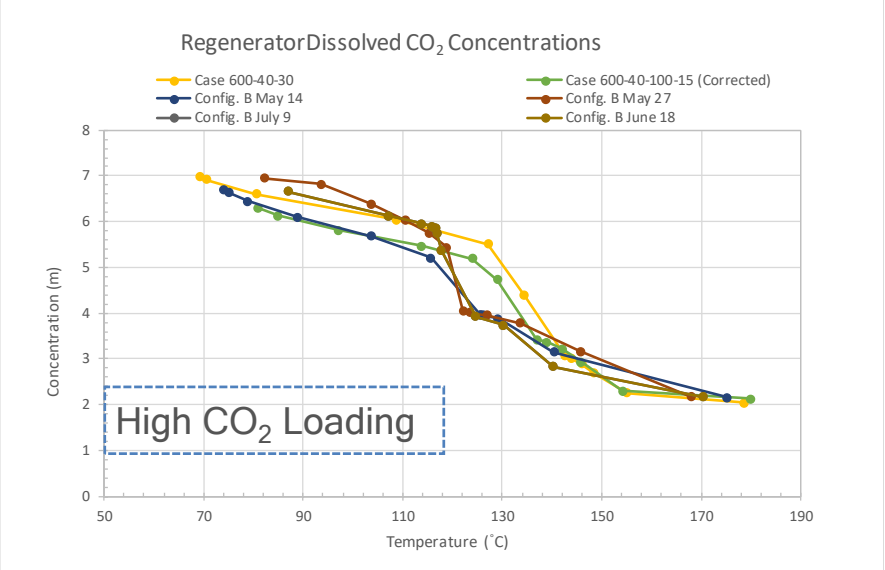
HAZOP (in preparation)

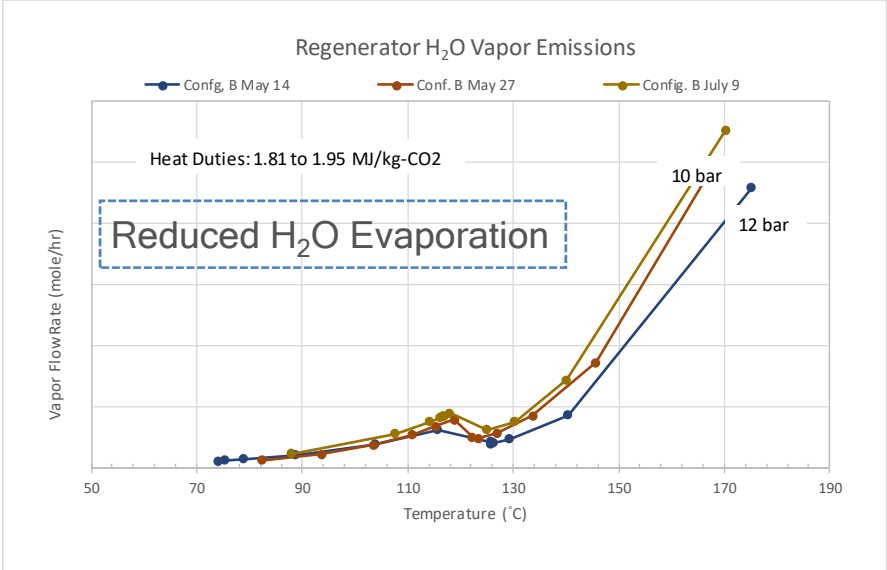


Selected Results from Flowsheet Modeling



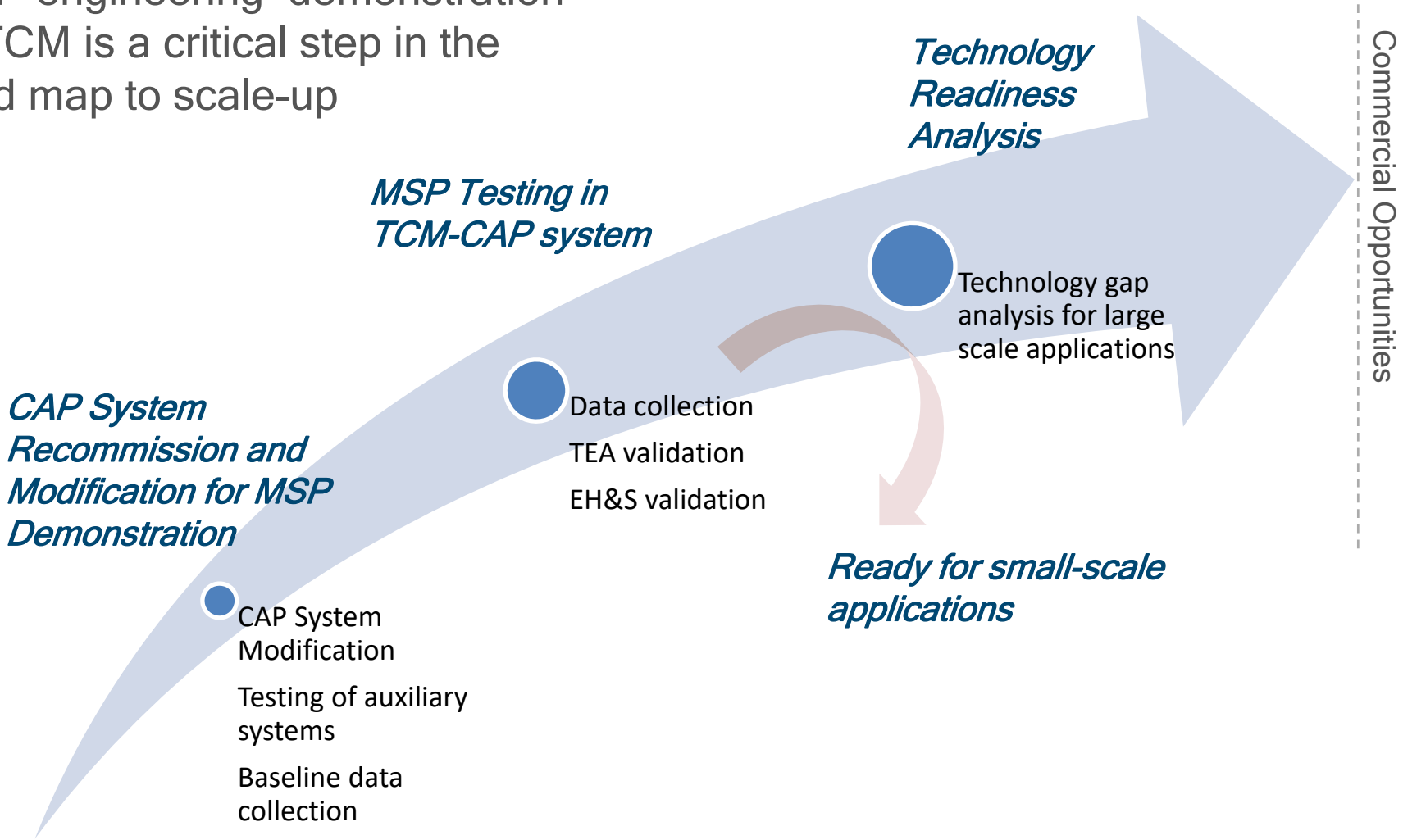






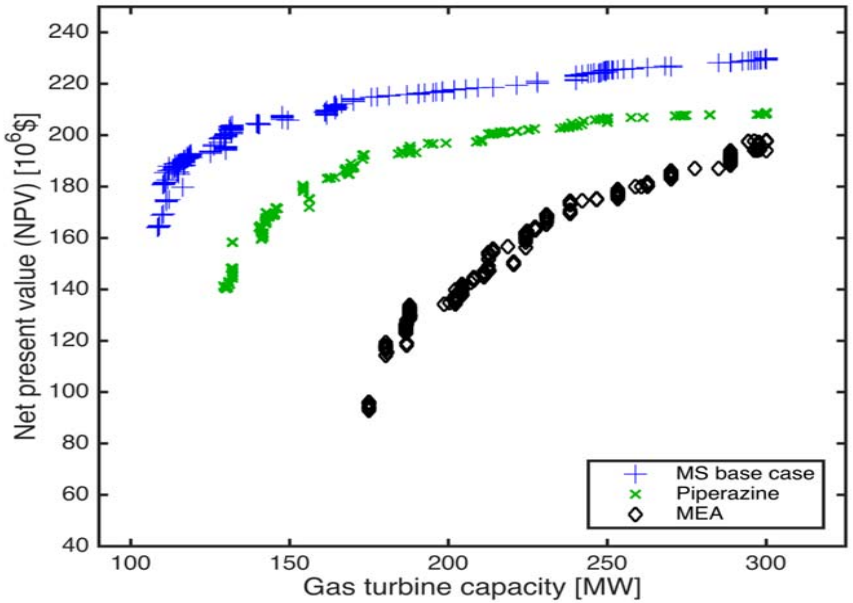
Pathway Toward Testing MSP at TCM and Beyond

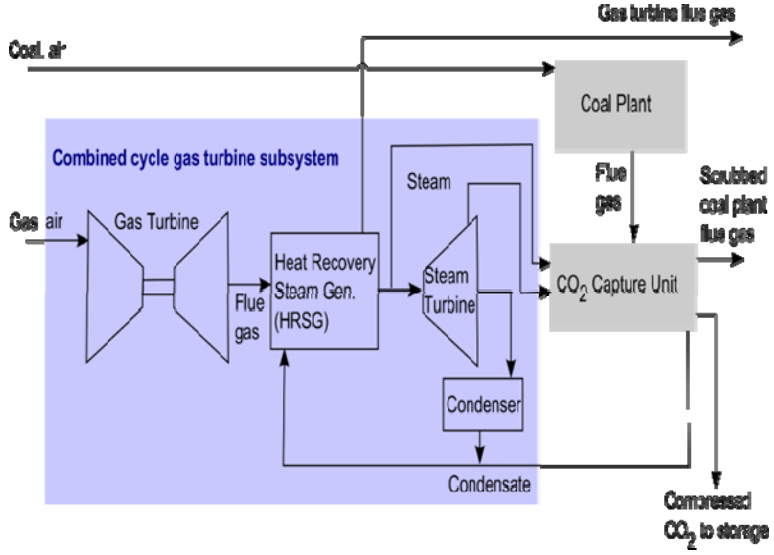
MSP engineering demonstration at TCM is a critical step in the road map to scale-up



SRI has the patent coverage for MSP in US, Japan and Europe

MSP Carbon Capture Technology Integration with the Power Plant





Comparison of MSP with amine systems. Left- Modeling of auxiliary gas fired CCS for retrofits of coal-fired power stations. Right -Schematic of the CCS enabled facility

2017 SRI International

Acknowledgements

2017 SRI International

Our Past and Current Partners in CO_2 Capture Technology Development

Teams for Mixed-Salt Related Activities

NETL (DOE)

- Andrew Jones, Steven Mascaro, Jose Figueroa, Lynn Brickett, John Litynski and other NETL staff members

SRI Team

- Indira Jayaweera, Palitha Jayaweera, Elisabeth Perea, Regina Elmore, William Olsen, Chris Lantman, Kelli Connolly, Lisa Wottrich and Rene Harmount

Host Site

- TCM (Bjørn-Erik Haugan, Jorunn Brigsten, Kjetil Hantveit, Gerard Lombardo, Muhammad Ismail Shah and others)

Other Collaborators and Contributors

- OLI Systems (Ron Springer, Prodip Kondu and Andre Anderko)
- POLIMI (Davide Bonalumi, Stefano Lillia and Gianluca Valenti)
- Stanford University (Adam Brant and Charles Kang)
- Aqueous (Kaj Thomsen)
- BHGE (Gianluca Difederico, and Olaf Stallmann)
- IHI Corporation (Shiko Nakamura, Okuno Shinya, Yasuro Yamanaka, Kubota Nabuhiko, and others)

Thank You

SRI International

Headquarters
333 Ravenswood Avenue
Menlo Park, CA 94025
+1.650.859.2000

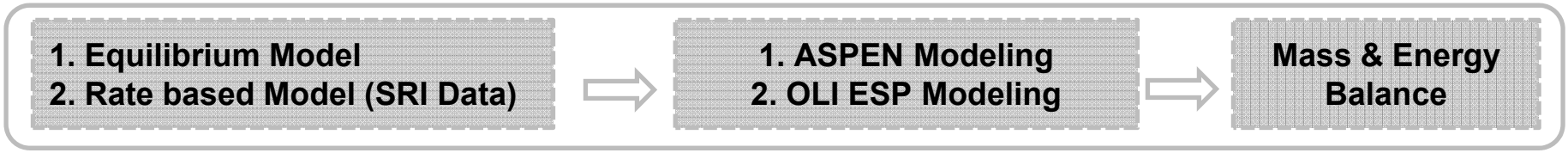
Additional U.S. and
international locations

www.sri.com

Contact:

Dr. Indira Jayaweera
Indira.jayaweera@sri.com
1-650-859-4042

Process Economic Data



Cost of Electricity (COE) Comparison

	NETL, Case 12 (2013)	NETL, Case 12B (2015)	SRI
Component, $/MWh	**Econamine**	**Cansolv**	**MSP**
Capital	66.4	72.2	57.1
Fixed	14.5	15.4	15.4
Variable	12.1	14.7	12.6
Fuel	35.3	30.9	32.3
Total (Excluding T&S)	**128.2**	**133.2**	**117.4**
CO_2 T&S	11.0	9.6	10.0
Total (including T&S)	**139.2**	**142.8**	**127.3**

Total Auxiliary Consumption [MWe]	112.8	91.0	72.0

- MSP has a COE almost 11% lower than CANSOLV
- The auxiliary consumption of the MSP technology are the lowest, mainly due to the lower CO_2 compression energy consumption in MSP compared to amine technologies.