Plant Barry CO_2 Capture Project

October 2015

MITSUBISHI HEAVY INDUSTRIES, LTD.

1. MHI's CO_2 Capture Technologies & Experience

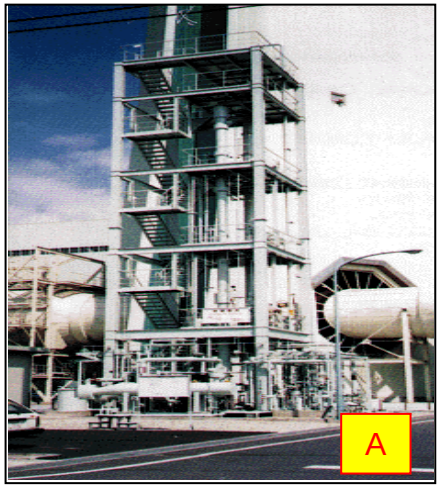
1.1 History of Development of MHI's CO_2 Capture Technology

1990	Started R&D activities with Kansai Electric Power Company (KEPCO)
1991	Started a 2 ton per day pilot plant at KEPCO's Nanko Power station
1994	Development of proprietary hindered amine solvent "KS-1®" and "KM CDR Process®" with KEPCO
1999	First commercial plant in Malaysia (200 ton per day, to enhance urea synthesis from the CO_2 recovered from a reformer flue gas)
2002	Started a pilot test for coal-fired power plant at MHI's Hiroshima R&D center
2003	**High energy efficiency -** Development of proprietary energy efficient process "Improved KM CDR Process"
2008	First commercial plant in Middle east (400 ton per day) which "Improved KM CDR Process" applied
2011	**World's First -** Started 500 ton per day fully integrated CCS demonstration plant with Southern Company for a coal-fired power plant at Alabama Power's James M. Barry Electric Generating Plant
2014	**World's Largest -** Received an order for a PCC plant of 4,776 ton per day for EOR mainly promoted by NRG Energy Inc. and JX Nippon Oil & Gas Exploration Corporation

1.2 MHI - R&D Strength & Experience

Deployment of R&D Facilities for specific CO_2 capture testing. More than 25 years R&D Experience

(A) 2.0 TPD Nanko Osaka pilot plant from 1991
(B) 1.0 TPD Hiroshima pilot plant
(C) 10 TPD Matsushima pilot for testing coal fired flue gas
(D) 500 TPD Barry CCS demonstration plant in Alabama, (25MW equivalent)



2.0TPD Nanko Pilot Plant
(Kansai Electric Power Co.)

1.0TPD Hiroshima Pilot Plant
(MHI' R&D Center)

10TPD Matsushima Pilot Plant
(J-Power)

500TPD Barry Demonstration Plant
(Southern Company)

1.3 MHI CO_2 Capture Plants Commercial Experience

- World leading large scale post combustion CO_2 capture technology licensor, with 11 commercial plants in operation from a variety of natural gas or heavy oil flue gas sources
- World's largest CCS plant is under construction in Texas.

1999
210 t/d Malaysia

2005
330 t/d Japan

CO_2 Recovery (CDR) Plant – IFFCO AonlaUnit (India)

2006
450 t/d India

CO_2 Recovery (CDR) Plant – IFFCO Phulpur Unit (India)

2006
450 t/d India

2009
450 t/d India

2009
450 t/d Bahrain

2010
400 t/d UAE

2010
240 t/d Vietnam

2011
340 t/d Pakistan

2012
450 t/d India

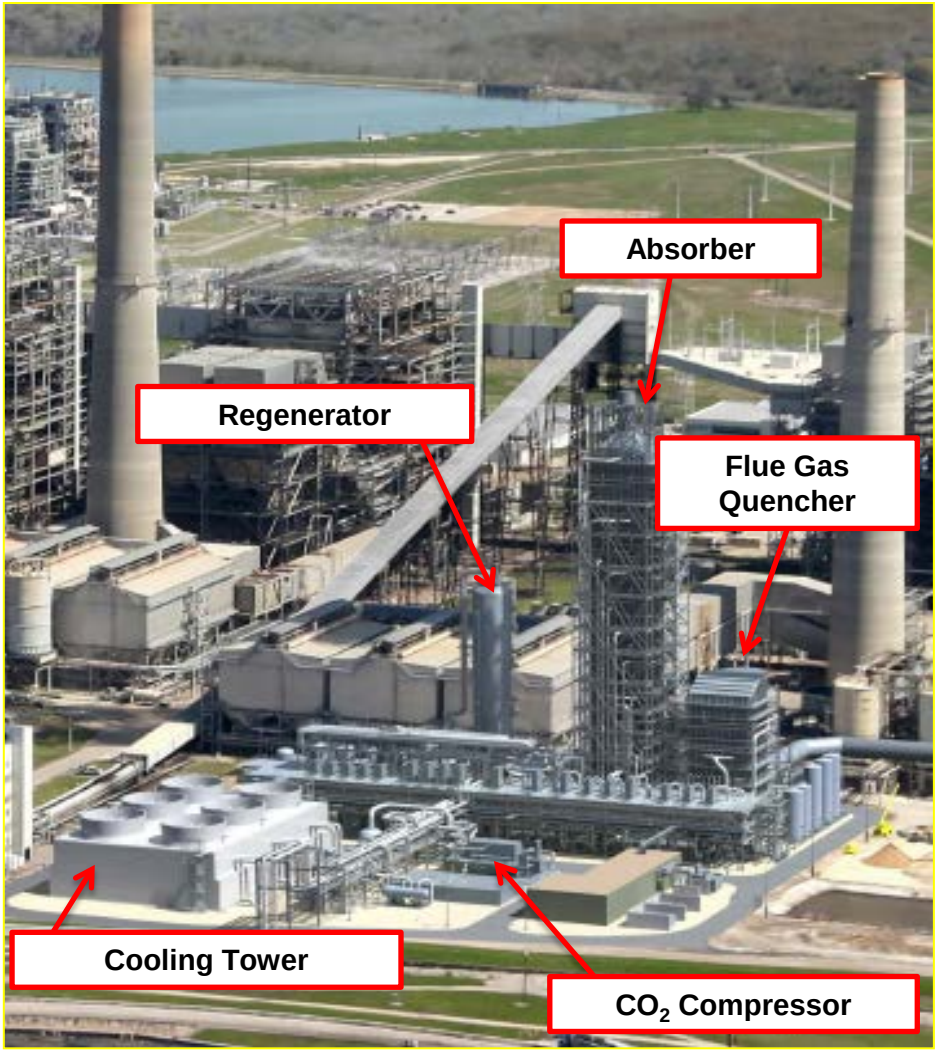
2014
500 t/d Qatar

2016
283 Mt/d Japan

1.4 Petra Nova CO_2 Capture Plant for CO_2-EOR

The world's largest CO_2 capture and compression plant from coal-fired power plant

- Project owner: Petra Nova, a partnership between NRG Energy, Inc. and JX Nippon Oil & Gas Exploration Corporation
- Location : NRG WA Parish Power Plant in Thompsons, TX.
- Flue gas source: Slipstream off of 650MW coal-fired boiler
- CO_2 concentration: 11.5%
- CO_2 capture capacity : 4,776 TPD (240MW equivalent)
- CO_2 capture ratio : 90%
- CO_2 Use : CO_2 EOR
- Pipeline : Approximately 81miles
- Injection Site: West Ranch oil field in Jackson County, TX
- Operation Start : 4th Quarter, 2016

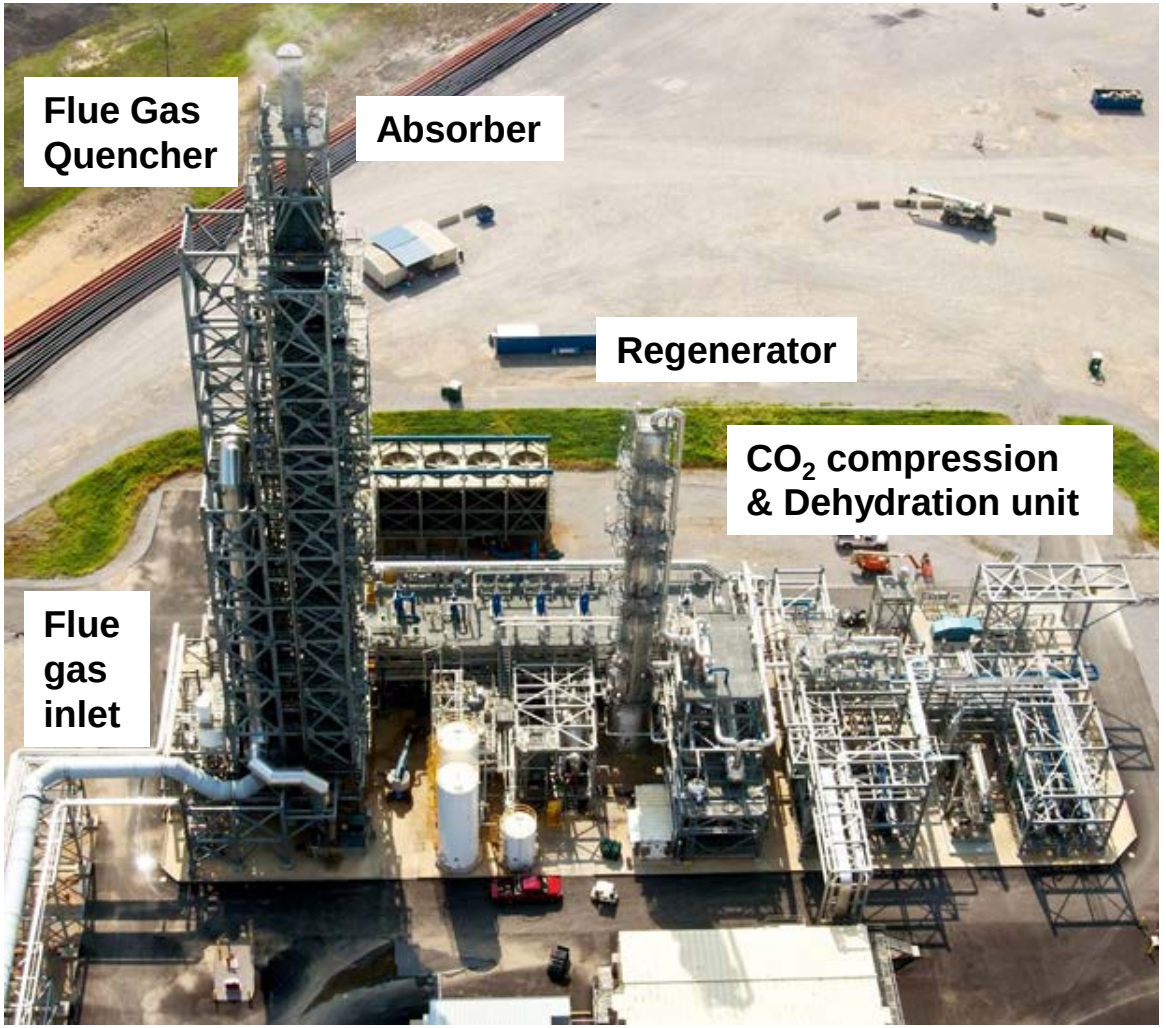


2. 500 TPD Barry Demonstration Plant

MITSUBISHI HEAVY INDUSTRIES, LTD.

2.1 Specification of Demonstration Plant

Southern Company Plant Barry CO_2 Demo Plant



Item	Description
Plant location	Mobile County (Alabama, U.S.A.)
Plant owner	Southern Company subsidiary Alabama Power
Process	KM CDR Process®
Absorption liquid	KS-1™ solvent
Plant scale	Corresponding to 25 megawatts (MW)
Flue gas amount	116,800 Nm^3/h
CO_2 concentration	10.1 mol%-wet
CO_2 capture capacity	500 tonnes/day (150,000 tonnes/year)
CO_2 capture ratio	90 percent

2.2 Test Items – Focusing from 2011 to 2013

Test Item	Main Results
Performance optimization	Achieved **0.95 ton-steam/ton-CO_2** by optimizing steam consumption
Emissions & waste streams monitoring	Successfully demonstrated amine emission reduction technologies under the various SO_3 concentration condition
Dynamic response test	Successfully demonstrated Automatic Load Adjustment & Optimized Operation Control System
Long term test validating equipment reliability and life	Achieved more than **100,000 metric tons of CO_2 injection** without any operational issues.

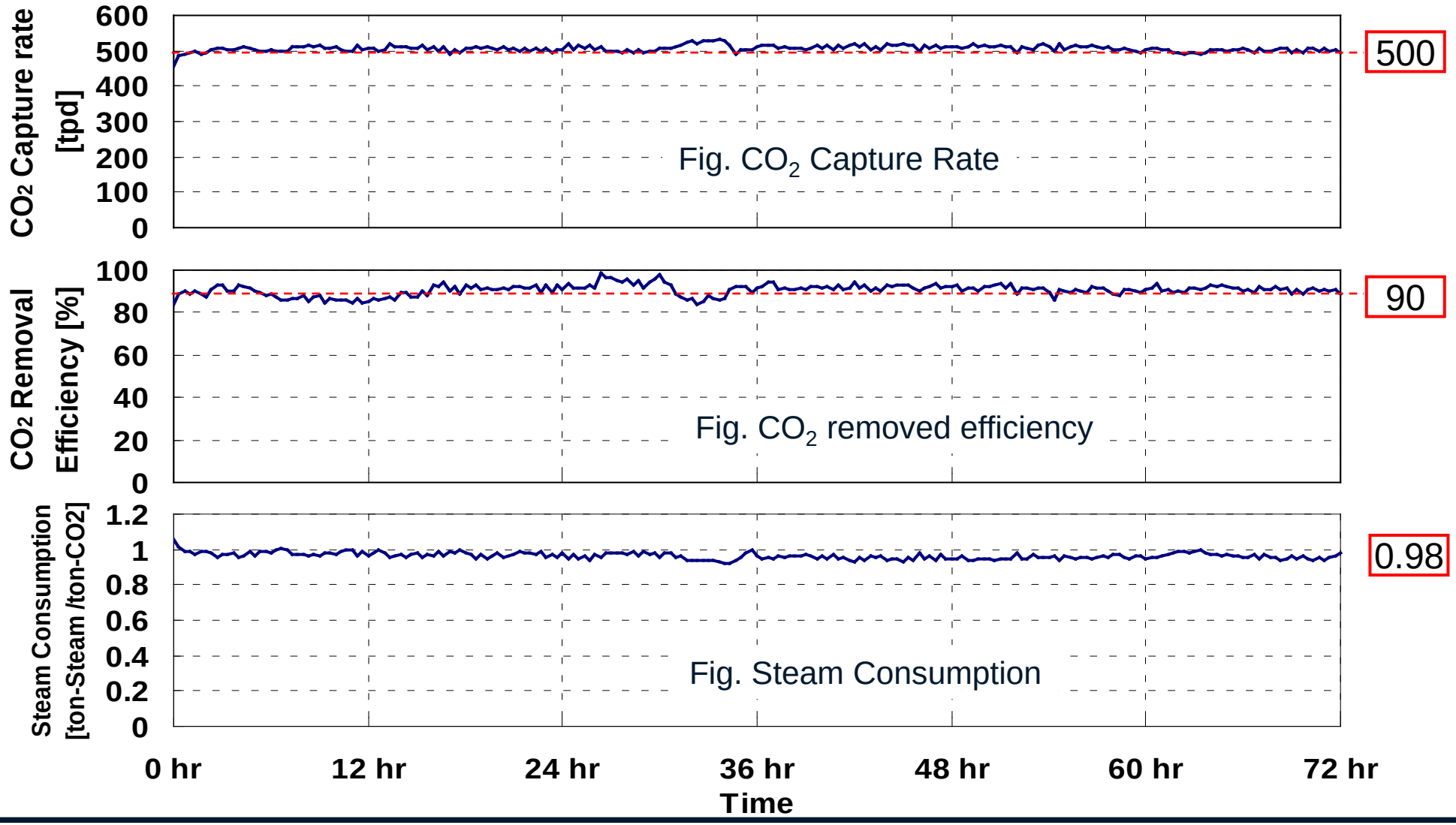
2.3 Plant Performance (1/3)

- **Flue gas CO_2 concentration varies based on boiler load**
- **KM-CDR® Process can be adjusted to achieve the desired CO_2 capture rate and production rate with varying boiler conditions**

		Base Case	High Efficiency Case	High Load Case
Flue gas condition	Flue gas flow rate [Nm^3/hr]	109,000	112,000	116,000
	CO_2 concentration at the Quencher Inlet [vol.% (w)]	10.8	10.5	10.8
Operation Results	CO_2 Capture rate [TPD]	**505**	**509**	**543**
	CO_2 removed efficiency [%]	**91**	**91**	**91**
	Steam Consumption [ton-steam/ton-CO_2]	0.98	0.95	1.02

2.3 Plant Performance (2/3) - Operation Data Trend

- Very stable at full load condition with CO_2 capture rate of >500tpd at 90% CO_2 removal
- Lower steam consumption compared with the MHI conventional process



2.3 Plant Performance (3/3) - Summary

- Gas In for CO_2 Capture Plant: June, 2011
- Commissioning of CO_2 Compressor: August, 2011
- Commissioning of CO_2 Pipeline: March, 2012

CO_2 Injection Pump (Denbury)

- CO_2 injection into underground formation started on August 20th, 2012 – as part of DOE funded SECARB project (World's Largest Integrated CCS from Coal-fired Power Plant)
- 100,000 metric tons of CO_2 injection was achieved on October 29th, 2013.

Items		Results
Total Operation Time *	hrs	12,400
Total Amount of Captured CO_2 *	metric tons	253,600
Total Amount of Injected CO_2 *	metric tons	126,900
CO_2 Capture Rate	metric tons per day	> 500
CO_2 Removal Efficiency	%	> 90

*** Operating Experience as of August 31, 2014 (End of Phase I Demonstration)**

*As of October 31th, 2013

2.4 Amine Emission Test Results

- Demonstrated MHI's advanced amine emission reduction system
- Amine emission was reduced by more than 90% in comparison with the conventional system under the presence of SO_3 in flue gas

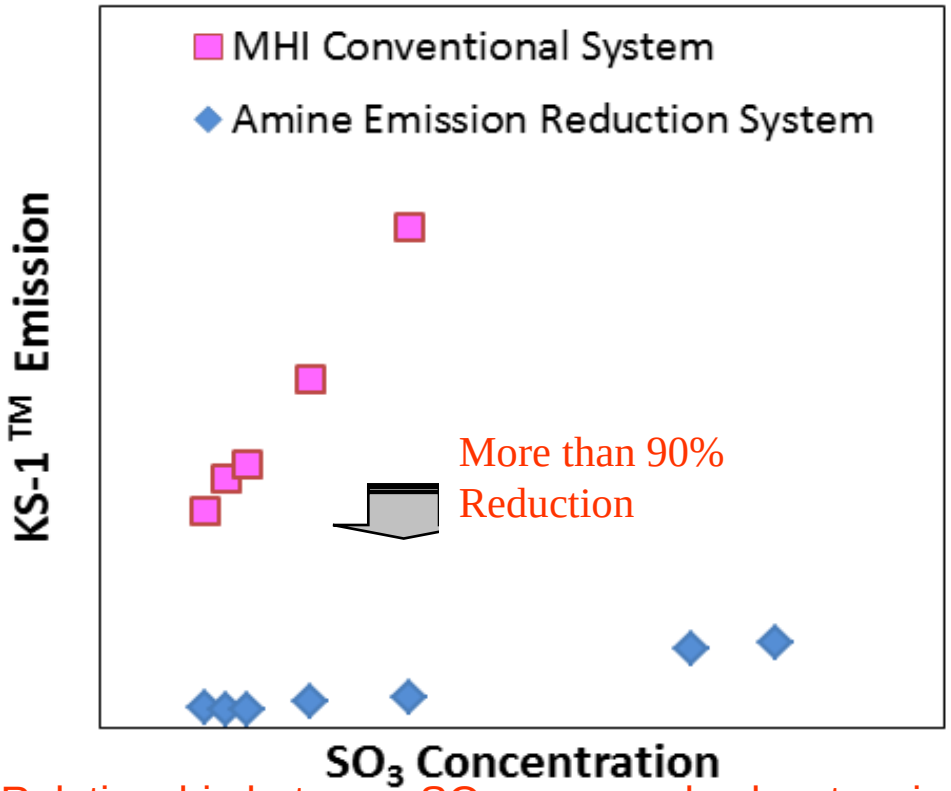


Fig. Relationship between SO_3 conc. and solvent emission

Fig. Absorber top

2.5 Dynamic Response Testing (1/3)

- Coal fired power plant changes the operation load frequently and the flue gas condition fluctuates

- Demonstrate Automatic Load Adjustment Control (ALAC) & Optimized Operation Condition Control (OOCC)

Automatic Load Adjustment Control (ALAC)	Optimized Operation Condition Control (OOCC)
Load following operation for; 1) CO_2 production demand 2) Flue gas flow rate change (Simulated boiler-load change)	Continuous optimization of the operation condition for; 1) CO_2 production demand 2) CO_2 recovery rate requirement (Simulated boiler-load change)

2.5 Automatic Load Adjustment Control (2/3)

- The load adjustment (ALAC) system was developed with MHI's dynamic simulator.
- The load control system for KM-CDR® process successfully followed the load change at 5% per minute without any adverse effect.

KM-CDR® Process load adjustment system is proven and ready for applications that involve load changing power plants.

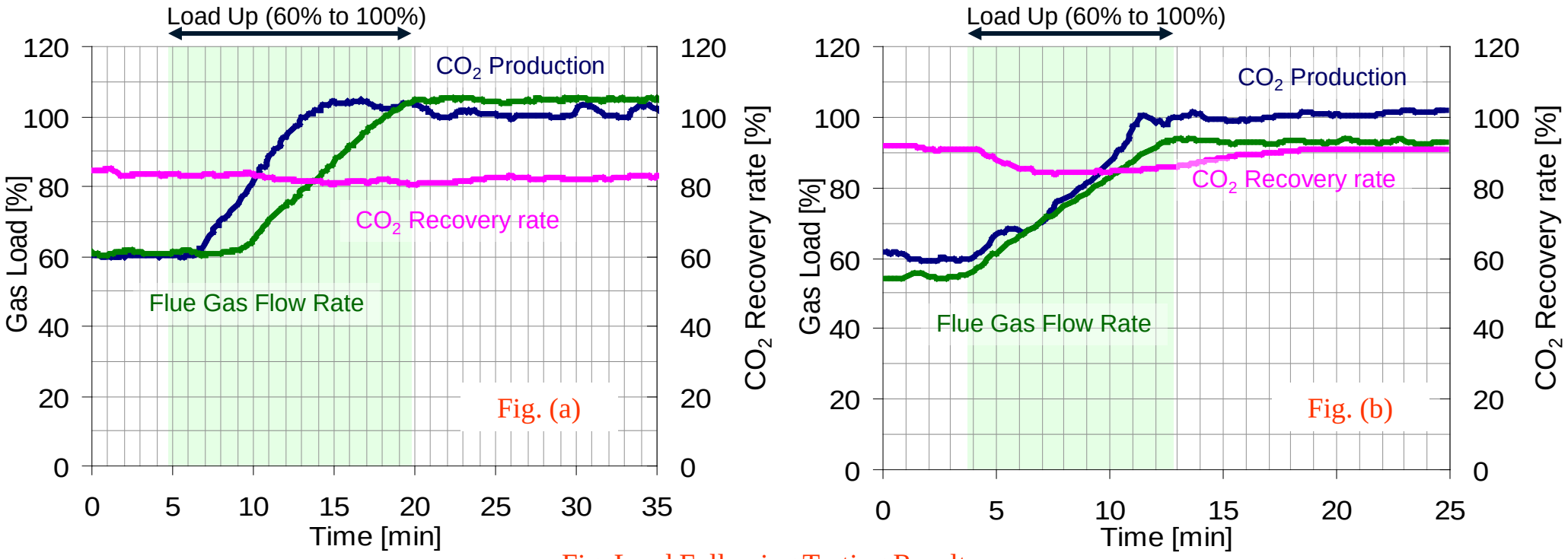


Fig. Load Following Testing Results
(a) CO_2 production demand following, (b) Flue gas flow rate following

2.5 Automatic Load Adjustment Control (3/3)

- The Optimized operation control (OOCC) system was added to the ALAC system.
- The system for KM-CDR® process automatically and continuously optimized the plant operation following to CO_2 production Demand or CO_2 recovery rate requirement.

KM-CDR® Process operation control system is also proven and ready for the integration with upstream and downstream facility.

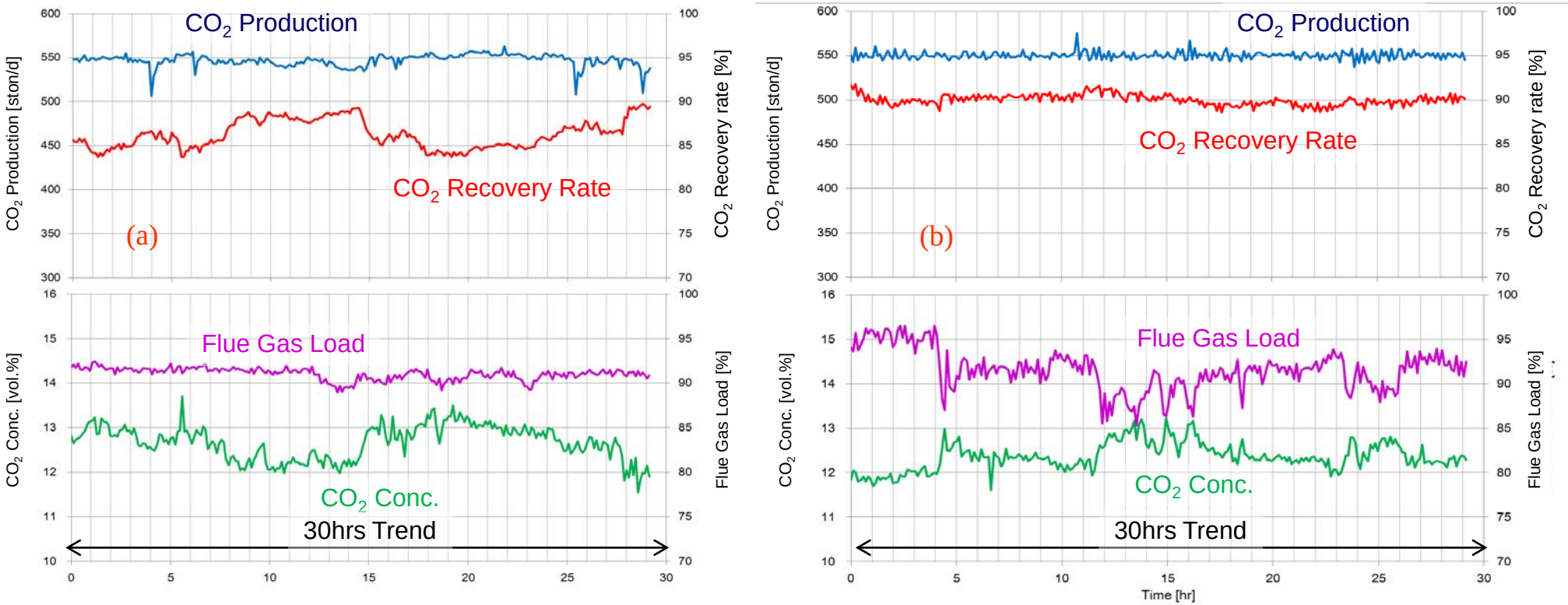


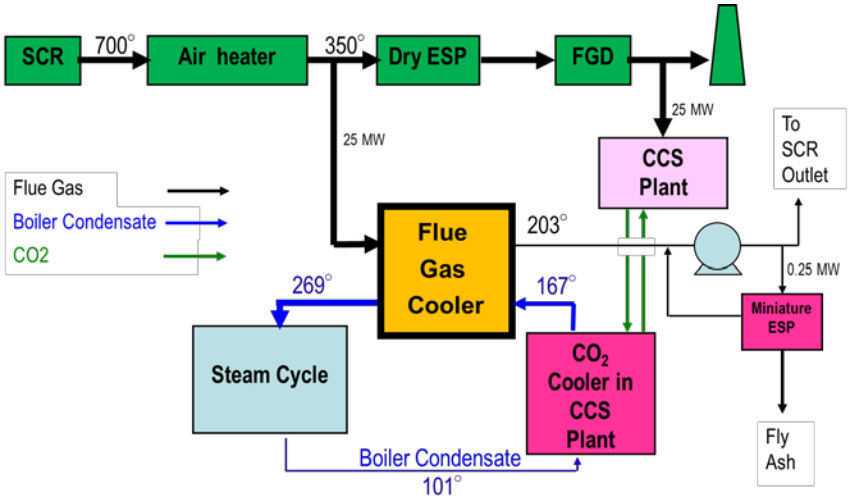
Fig. Comparison between manual operation and optimized operation control
(a) Manual operation, (b) Optimized operation control system (CO_2 Production Control Mode)

3. HES Demonstration Project

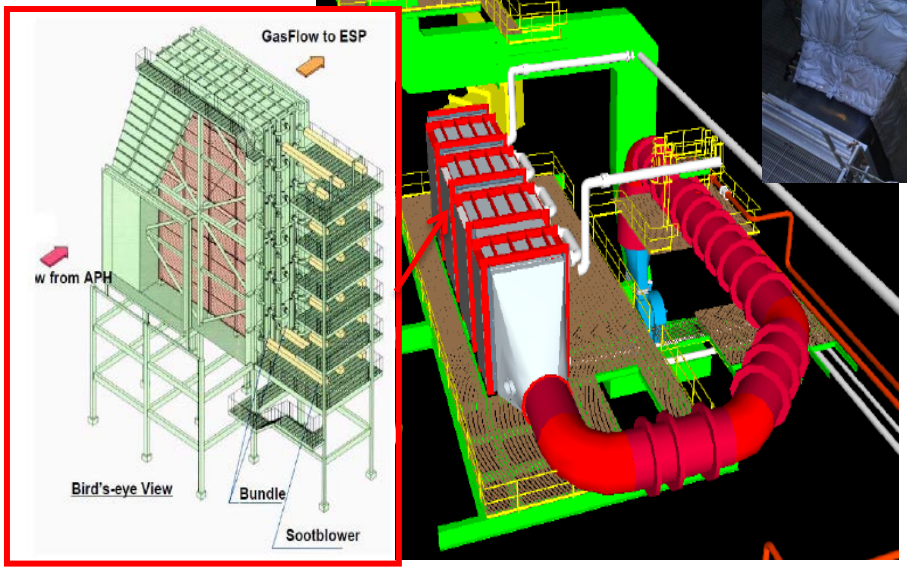
MITSUBISHI HEAVY INDUSTRIES, LTD.

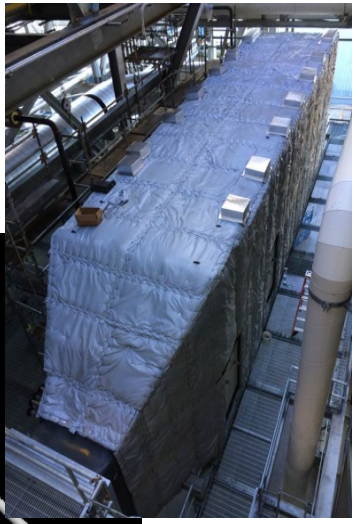
3. HES Demonstration Project

- Outline of Project
  - DOE funded 25 MW pilot demonstration project for heat integration system with CCS plant
  - Integrated with MHPS's HES and MHI's 500 TPD CCS Plant at Plant Barry circulating BFW between host site steam cycle, CCS and HES
  - Energy efficiency improvement and tangential benefits (removal improvement of PM, SO_3, Hg, Se, etc.) were evaluated



25 MW Pilot Test Facilities





Flue Gas Cooler (Heat Extractor) on 25 MW Pilot

3.1 Test Result - Performance

- Confirmed heat integration performance
  - 240-300 MMBTU/hr heat recovery for 550 MW base plant
  - Up to 65% reduction of FGD makeup water

Source	Data collected	Units	w/o HES heat integration	w/ HES heat integration	w/ HES heat integration
			12/16/2015	9/9/2015	9/1/2015
FGC	Flue gas flow rate	scfm	49,998	60,640	60,631
	Flue gas temp FGC inlet	degF	288	323	314
	Flue gas temp FGC outlet	degF	NA	200	186
	Recovered heat	MMBtu/h	NA**	8.66	9.09
CO_2	Flue gas flow rate*	scfm	73,800	73,800	73,800
	CO_2 removal performance*	%	> 90	> 90	> 90
	BC flow rate	stph	0	38	50
	BC temp CO_2 cooler inlet	degF	NA	128	123
	BC temp CO_2 cooler outlet	degF	NA	167	167
	Recovered heat	MMBtu/h	NA	2.9	4.4
Plant	Boiler Load net	MW	721	783	680
	BC flow rate	stph	0	38	50
	BC feed temp	degF	NA	128	123
	BC return temp	degF	NA	280	264
	Recovered heat	MMBtu/h	NA	11.1	13.6
	Recovered heat for 550 MW base plant	MMBtu/h	NA	244	300

3.2 Test Result - Durability

- Confirmed no significant corrosion on tube bundles
  - 4 wks w/o SO_3 injection, 3 wks w/ SO_3 injection
  - Detailed analysis is in progress

(a) Before operation

(b) October, 2015

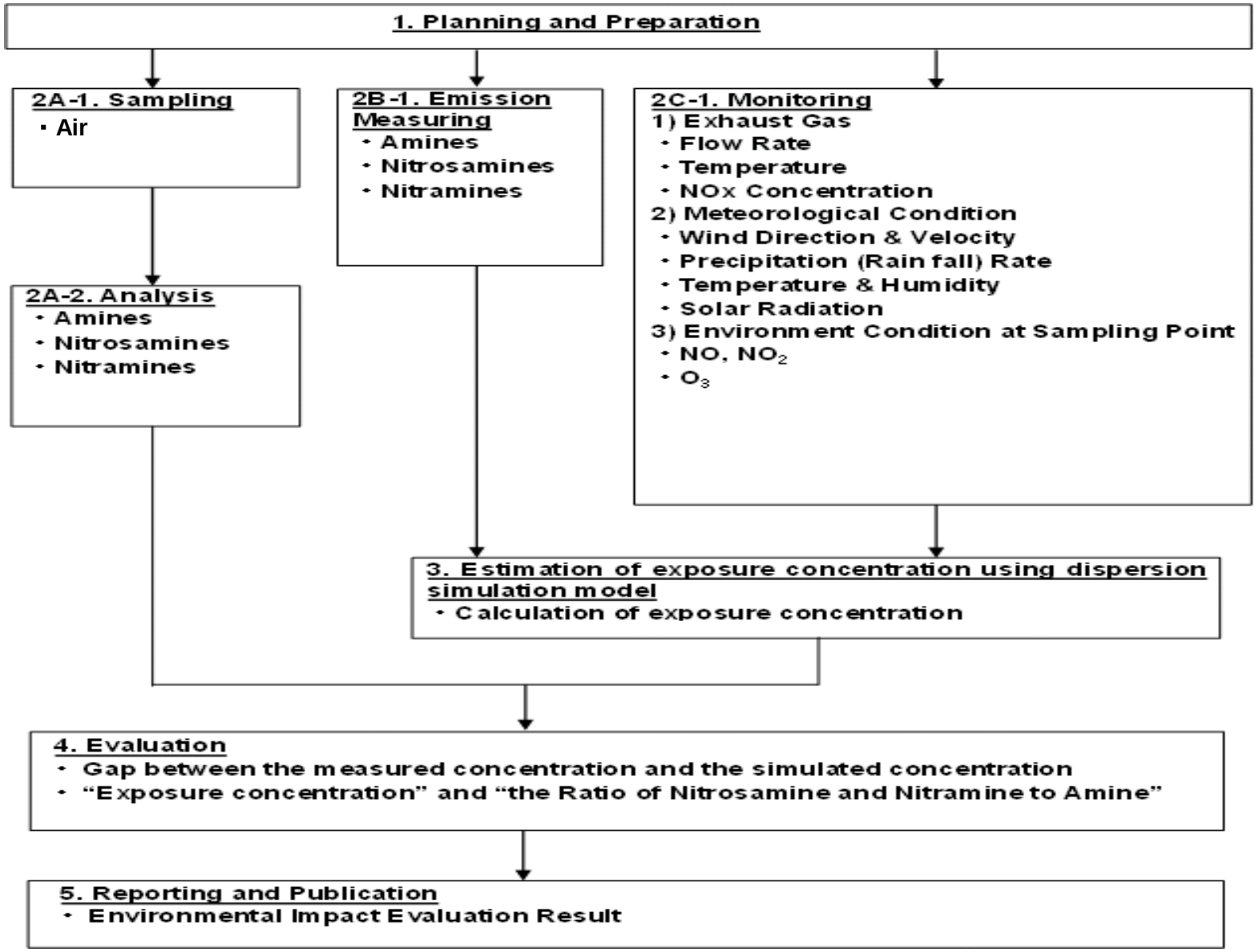
(c) January, 2016*

*The remaining fly ash can be easily removed by soot-blowers.

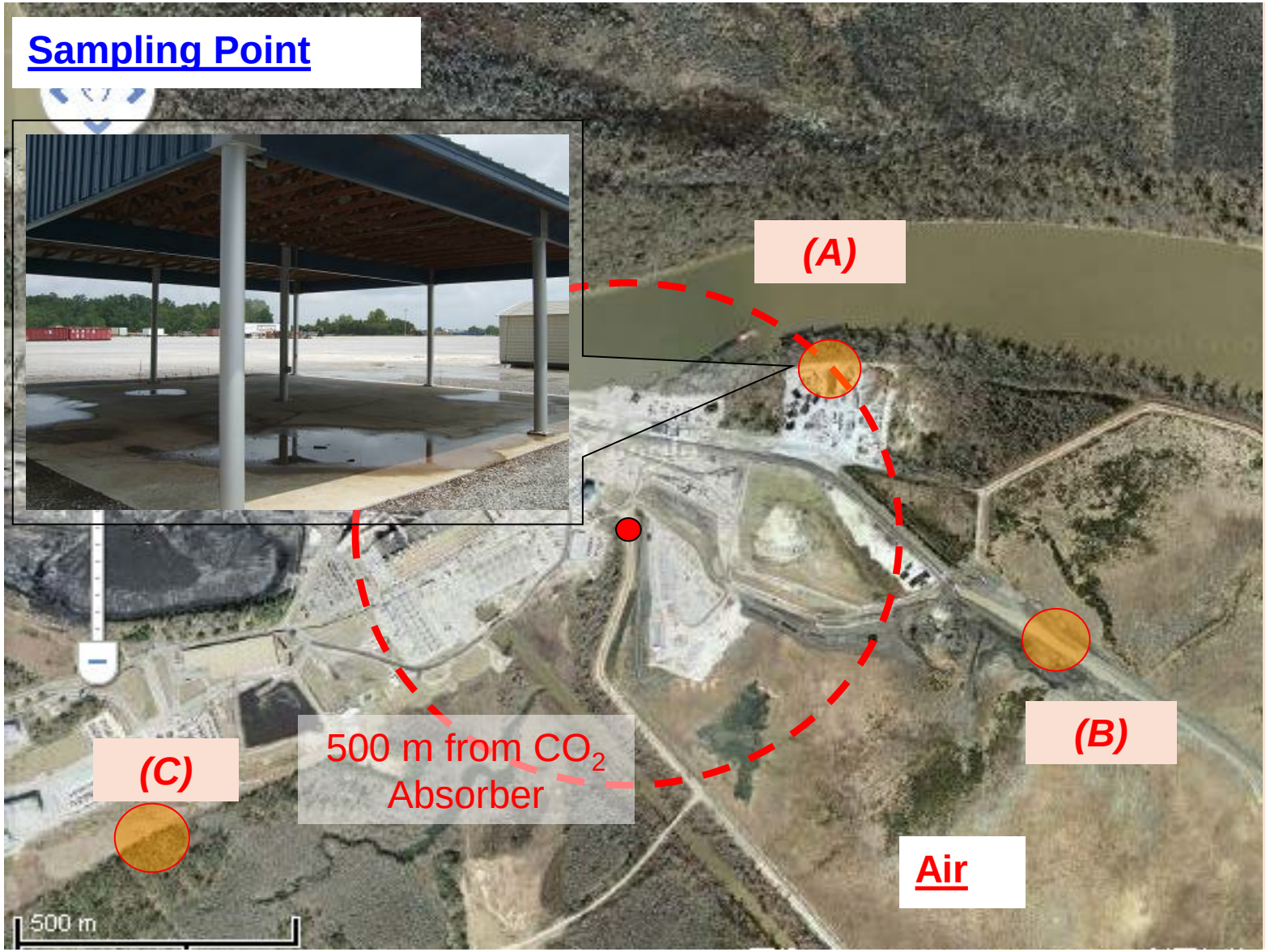
4. Environmental Monitoring

MITSUBISHI HEAVY INDUSTRIES, LTD.

4.1 Environment Monitoring (1/2) - Activity



4.1 Environment Monitoring (2/2) - Sampling Points



4.2 Monitoring Result

1) NA & NT were also measured in the air near the CO2 Capture plant inside Barry Power Plant. Confirmed that Concentration of NA & NT is less than 0.3 ng/Nm3 that NIPH recommends as allowable figures.

2) Carry out dispersion model calculation and compared the actual result. MHI consider that the dispersion model considering chemical reaction rate is appropriate to evaluate the environmental impact by amine emission.

5. Next Path

- **Phase 1 DOE NETL Carbon Capture Program, Large-Pilot Scale Post-Combustion: Completed**
- **Phase 2: Planned**

Program

✓ **Built-in Reboiler**
Replace regenerator reboiler & stripper with integrated unit

✓ **Particulate Matter (PM) Management**
Determine maximum allowable particulate matter concentration

✓ **New Solvent A Testing**
Replace KS-1™ solvent with improved amine-based New Solvent A

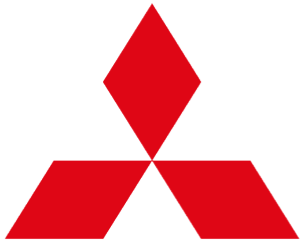
=> *Reduce capital & operating cost of CCS*

6. Summary

MITSUBISHI HEAVY INDUSTRIES, LTD.

Summary

- Plant Barry captured Total **253,600** metric tons of CO_2, and total 126,900 metric tons of CO_2 were injected to underground as of August 31, 2014
- Demonstrated stable performance at full load condition with CO_2 capture rate of 500 TPD at 90% CO_2 removal.
- The following successful demonstration results were obtained.
  - New amine emission reduction technologies achieved significant reduction (More than 90% reduction).
  - Automatic Load Adjustment (ALAC) System stably controlled load changing at a rate of 5%/min. Optimized Operation Control (OOCC) System continuously optimized the operation following the changing of flue gas condition or CO_2 production demand.
- Southern Company and MHI completed DOE funded heat integration project to further improve net plant efficiency.
- Southern Company and MHI completed Phase 1 DOE NETL Carbon Capture Program, Large-Pilot Scale Post-Combustion. Phase 2 is being planned.



MITSUBISHI
HEAVY INDUSTRIES, LTD.

Our Technologies, Your Tomorrow

MITSUBISHI HEAVY INDUSTRIES, LTD.