Reducing CO_2 capture cost by 30% using Advanced KM CDR Process™

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Outline

- ✓ Introduction
- ✓ KM CDR Process™ – Features & Experiences
- ✓ Advanced KM CDR Process™
- ✓ New KS-21™ Solvent Development
- ✓ Summary

Introduction

Mitsubishi Heavy Industries

- Established in 1884
- Number of employees: 80,652 (consolidated)
- Annual Revenue (2016): USD $36.6 billion

Power Systems

GTCC Power Plant

J-series Gas Turbine

Compressor

Industry & Infrastructure

Transportation system

Chemical Plant

Passenger Ship

Machine Tool

Flue gas CO_2 Recovery

Forklift Truck

Aircraft, Defense & Space

H-II Rocket

Space Station

Air Craft

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KM CDR Process™ – Features & Experiences

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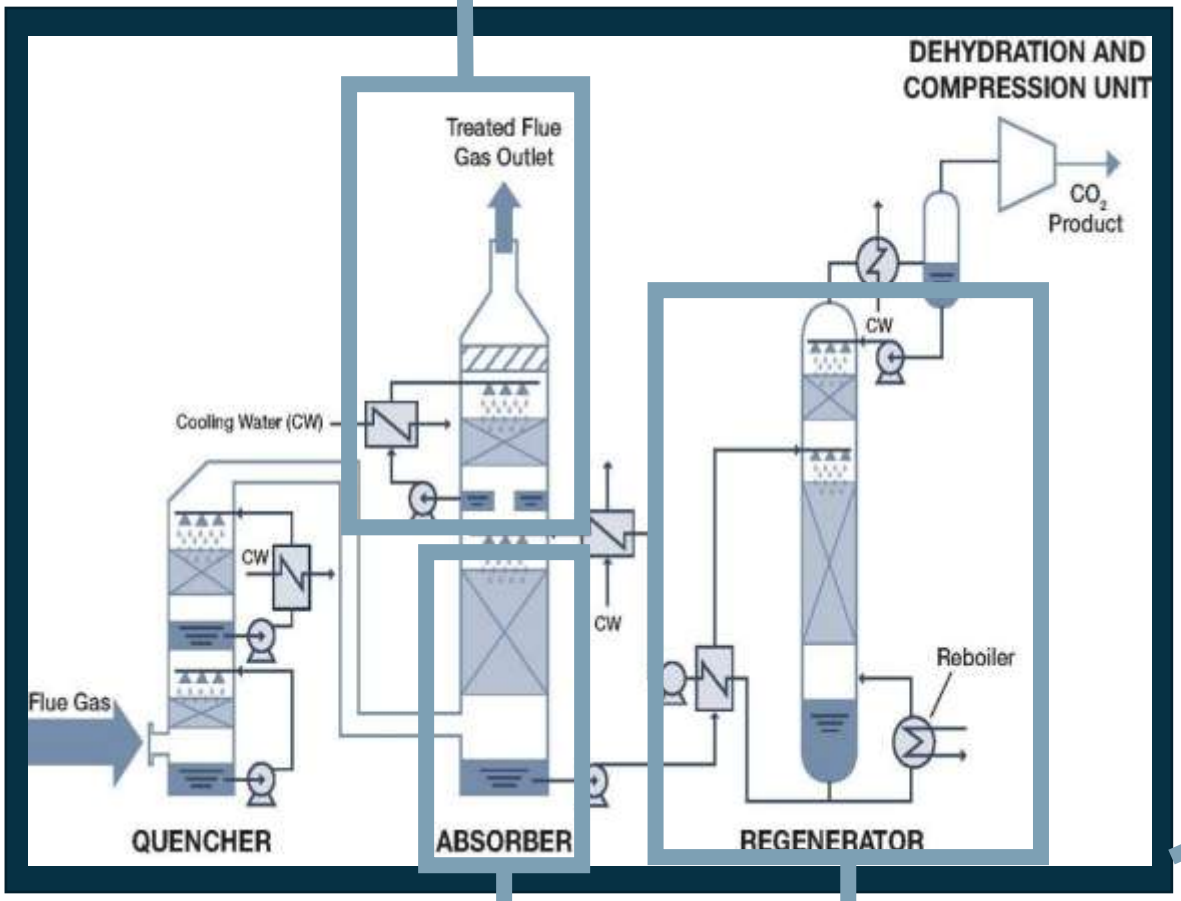
KM CDR Process™ Overview and Features

Amine washing system reduces VOC emissions and amine loss



KS-1™ solvent with high CO_2 capacity, low degradation, and low regeneration energy

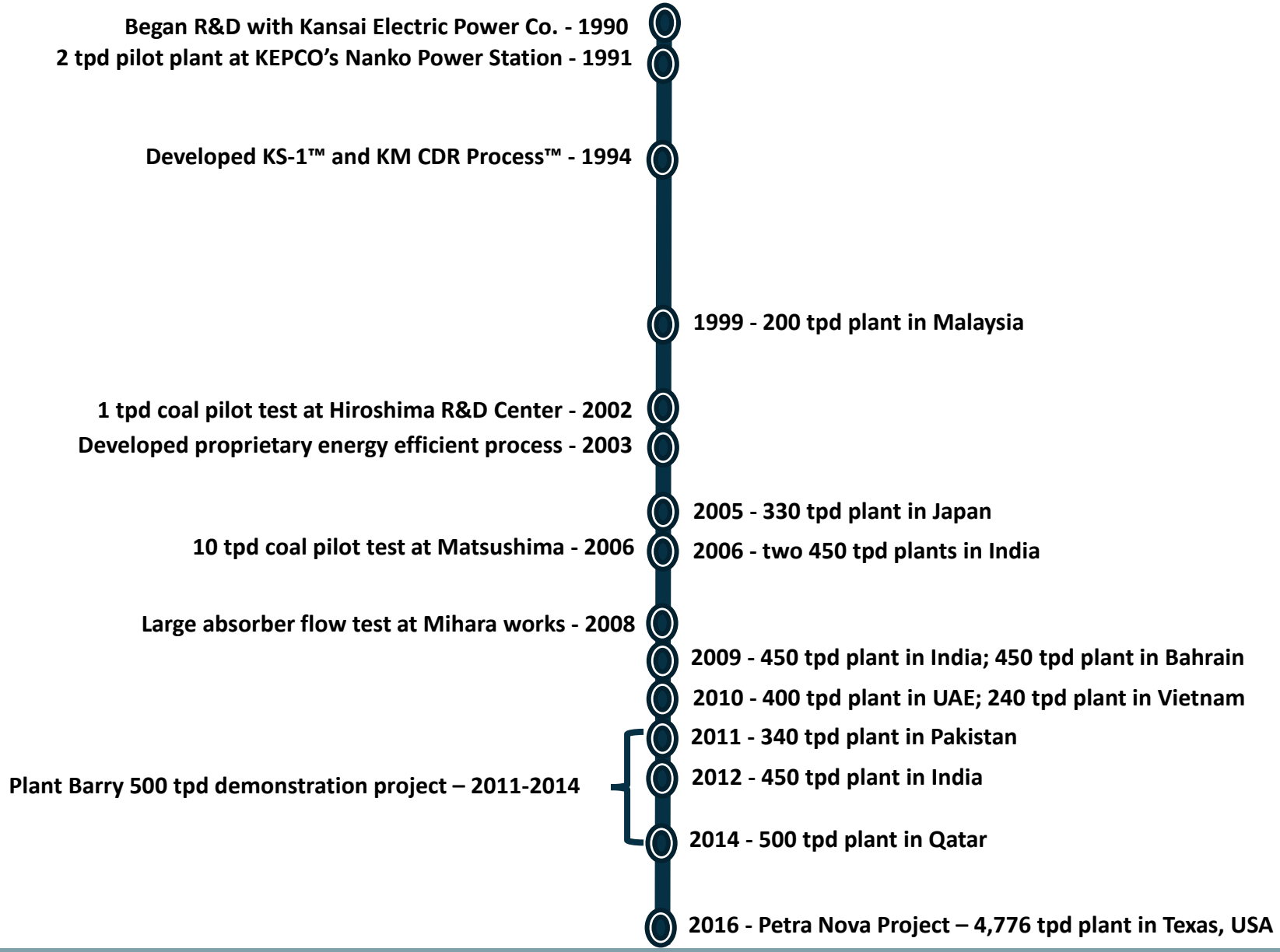
Heat integration system to reduce steam consumption

- ✓ **KM CDR Process™ = *Kansai Mitsubishi Carbon Dioxide Recovery Process***
- ✓ **Jointly Developed by MHI Engineering & Kansai Electric Power Company (KEPCO)**
- ✓ **Amine-based technology**
- ✓ **Capable of capturing ~90+% CO_2 from combustion gas sources for variety of usages such as EOR*, Urea & Methanol production and other general use.**
- ✓ **Proprietary features developed over 28 years of experience**

*** EOR = Enhanced Oil Recovery**

- Automatic load adjustment control
- Amine filtration and purification systems
- Proven tower design for even gas/liquid distribution

KM CDR Process™ Technology Development Timeline



What's Next for KM CDR Process™?

Plant Barry 500 tpd demonstration project – 2011-2014

- 2011 - 340 tpd plant in Pakistan
- 2012 - 450 tpd plant in India
- 2014 - 500 tpd plant in Qatar
- 2016 - Petra Nova Project – 4,776 tpd plant in Texas, USA

Advanced KM CDR Process™ using New KS-21™ solvent

- ✓ Multiple new solvent formulations have been evaluated.
- ✓ New Solvent has advantages over KS-1™ that help reduce overall capital and operating costs.
- ✓ Pilot testing is completed.

Parameters	KS-1™	New Solvent
Volatility	100	50-60
Thermal degradation rate	100	30-50
Oxidation rate	100	70
Heat of absorption	100	85

Cost Reduction

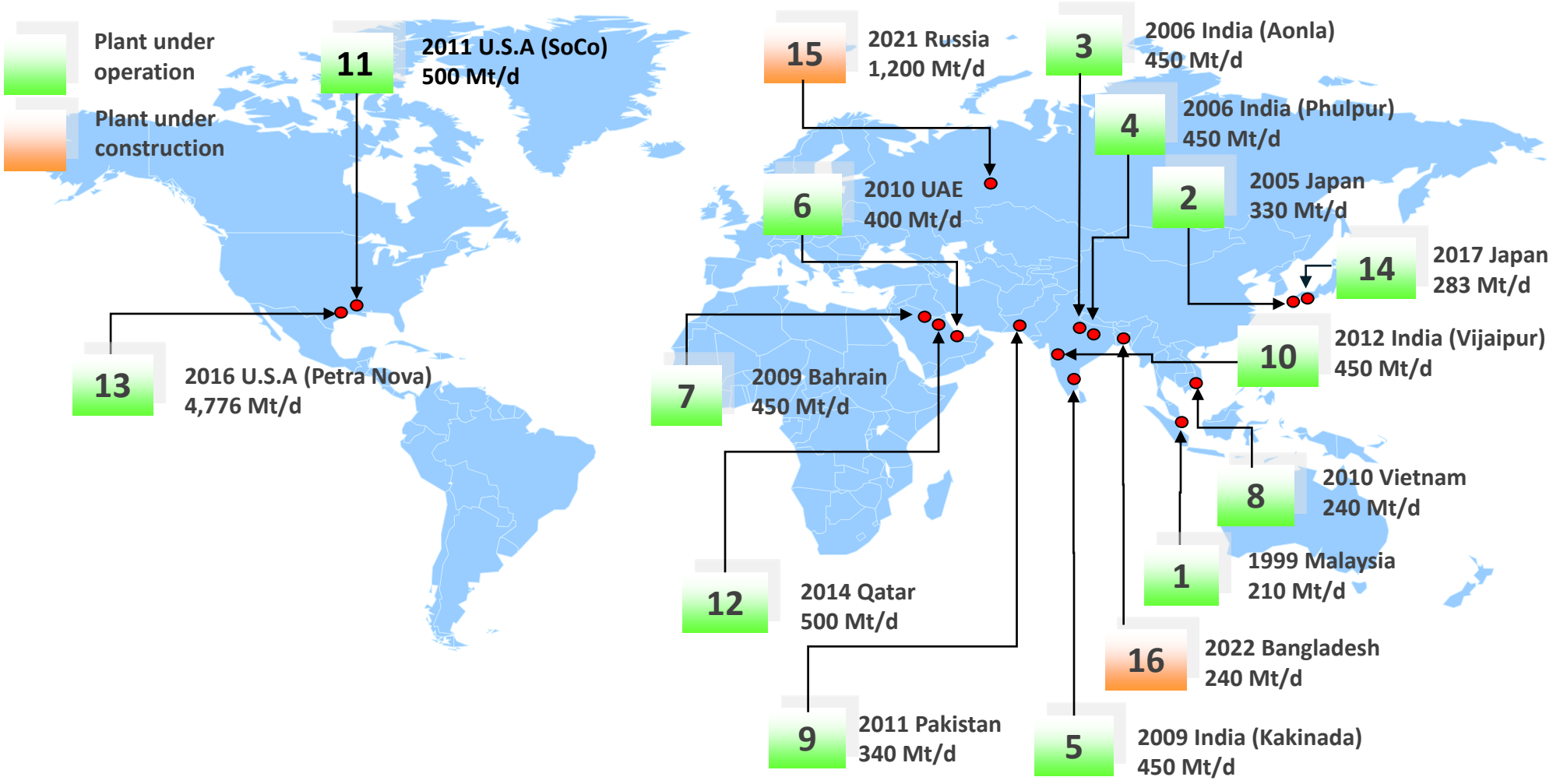
- ✓ Utilizing Advanced KM CDR Process™
- ✓ Modularization for Large and Middle size unit

Design Standardization

- ✓ Deliver the next 10,000+ tpd systems by reducing overall project cost and schedule

Delivery Record of KM CDR Process™

- **World's largest delivery of CO_2 capture plant for over 100 tpd capacity; 13 plants under commercial operation and 2 under construction**



Commercial Plants of KM CDR Process™

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World's leading large scale post-combustion CO_2 capture technology licensor

13 plants in operation and 2 under construction, from a variety of natural gas, heavy oil, and coal flue gas sources.

1999
210 t/d Malaysia

2005
330 t/d Japan

2006
450 t/d 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
4,776 t/d U.S.A.

2017
283 t/d Japan

2021
1200 t/d Russia

2022
240 t/d Bangladesh

Commercial Plants of KM CDR Process™

- ✓ Commercialized since 1999
- ✓ Various flue gas sources: Natural gas, heavy oil, and coal

Year of Delivery	Country	Flue Gas Source	CO_2 Capacity (TPD)	Application
1999	Malaysia	NG Fired Furnace	210	Urea Production
2005	Japan	NG and Heavy Oil Boiler	330	General Use
2006	India	NG Fired Furnace	450	Urea Production
2006	India	NG Fired Furnace	450	Urea Production
2009	India	NG Fired Furnace	450	Urea Production
2009	Bahrain	NG Fired Furnace	450	Urea Production
2010	UAE	NG Fired Furnace	400	Urea Production
2010	Vietnam	NG Fired Furnace	240	Urea Production
2011	Pakistan	NG Fired Furnace	340	Urea Production
2012	India	NG Fired Furnace	450	Urea Production
2014	Qatar	NG Fired Furnace	500	Methanol Production
2016	USA	Coal-Fired Boiler	4,776	Enhanced Oil Recovery
2017	Japan	Gas Fired Furnace	283	General Use
2021	Russia	NG Fired Furnace	1,200	Urea & melamine Production
2022 (Planned)	Bangladesh	NG Fired Furnace	240	Urea Production

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Advanced KM CDR Process™

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Background & Motivation

- ✓ KM CDR Process™ using KS-1™ is a fully commercial proven, however further reduction of CO_2 capturing cost is desirable to make more CCS or CCUS projects realize.

DOE/NETL CO_2 Cost Goal
2020 2nd Generation:
$40/ton
2025 Transformational:
Less than $40/ton

- ✓ Advanced KM CDR Process™ is developed as MHI's next-generation process following after KM CDR Process™ technology
- ✓ Commercialization is coming soon. Expects to offer for new commercial projects in 2019.

Feature of Next-generation CO_2 capture process

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✓ Advanced KM CDR Process™

- 30% CAPEX reduction compared to conventional KM CDR process™

✓ Improvement from new technology and lessons learned

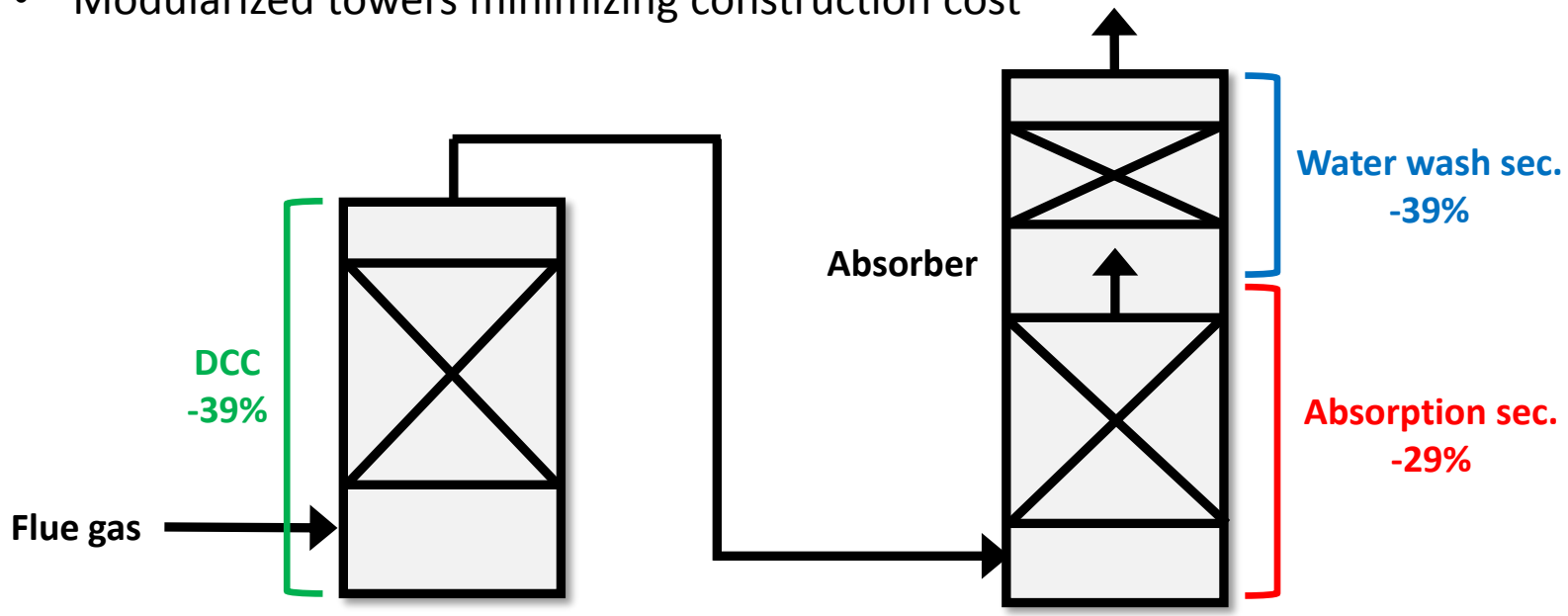
- Reduced size of DCC and Absorber
- Reduced design margin
- Compact layout and modular design
- Comparable utility consumptions (no OPEX-CAPEX tradeoffs)
- Automatic operation system

✓ Apply New KS-21™ solvent

- Reduced solvent consumption
- Less CO_2 compression power due to higher Regeneration pressure

Reduced size of DCC & Absorber

- ✓ **DCC and Absorber are the major cost centers (>30% of CAPEX)**
- ✓ **Validated performance & reduced redundancy**
  - Validated gas-liquid distribution and packing performance
  - Optimized absorption packing height and configuration
  - Optimized proprietary water wash system
- ✓ **Compact and modular design**
  - Integrated DeSOx and cooling section in DCC
  - Modularized towers minimizing construction cost



Reduced design margin

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- ✓ **Process redundancy & risks are significantly reduced after large-scale unit experience**
- ✓ **Filtration system:**
  - Validated PM capture rate and filtration efficiency
- ✓ **Heat exchangers:**
  - Reduced size by enhanced heat transfer using higher pressure drop
- ✓ **Pumps & Tower internals:**
  - Reduced tower height and process complexity

Cost Relative to conventional	Conventional	Advanced KM CDR Process™
Pumps	100	49
Heat exchangers	100	80
Tower internals	100	74
Filtration system	100	43
Tanks	100	74

Compact layout and modular design

✓ Modularization

- Pipe rack, heat exchanger/pipe and pump/pipe are fabricated in shop as skids to reduce on-site fabrication, reducing construction labor hours by 60% (excluding large towers)
- In-shop fabrication improves productivity and facilitates schedule and budget control

✓ Optimized plot plan and minimized footprint

- Minimized footprint reduces concrete, structural steel and piping material, resulting lower construction cost.

Spec Relative to conventional	Conventional	Advanced KM CDR Process™
Footprint (% in m^2)	100	75
Structural steel (% in tonne)	100	76
Piping (% in tonne)	100	79

Total CAPEX reduction

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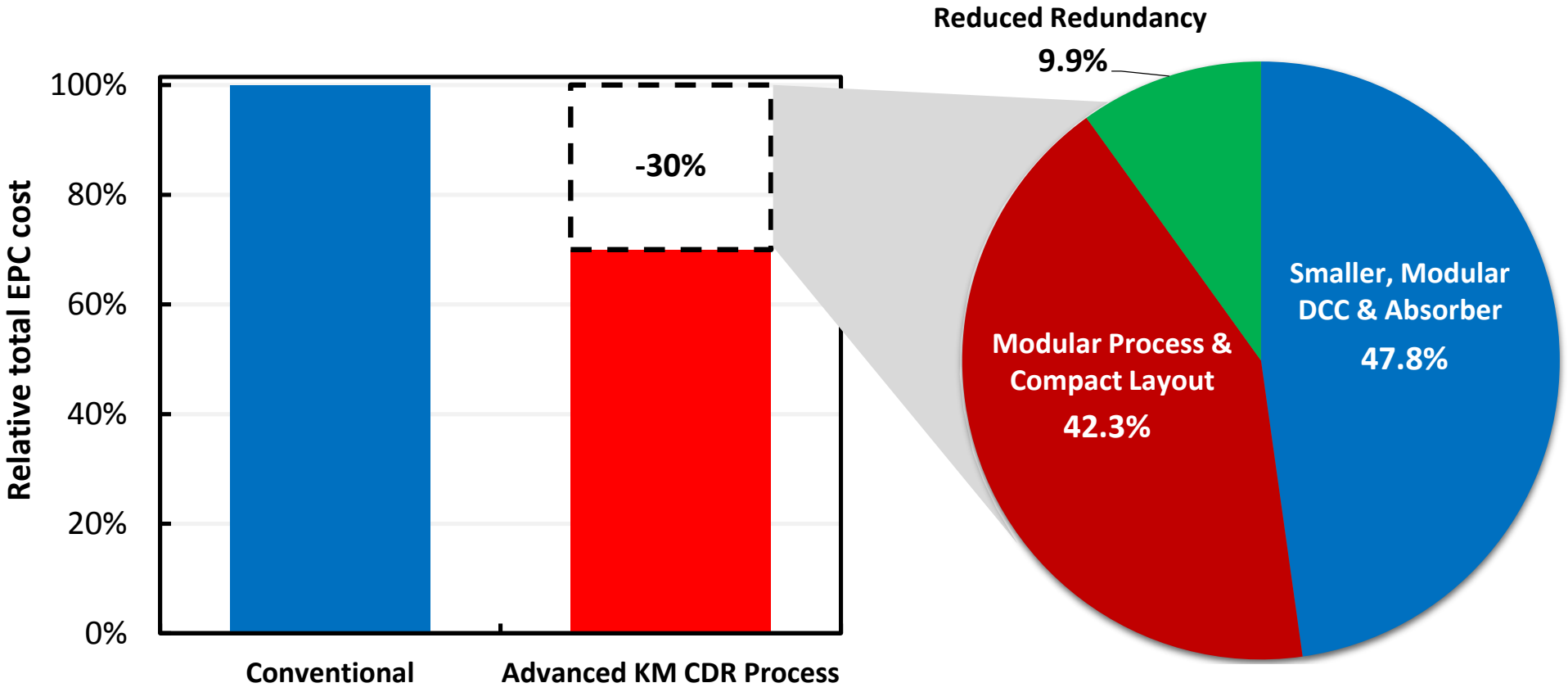
✓ The Advanced KM CDR Process™ reduces total EPC cost by 30% and is ready for new commercial projects



Remark: The CAPEX depends on specific condition, and the above result may differ for specific project

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New KS-21™ Solvent Development

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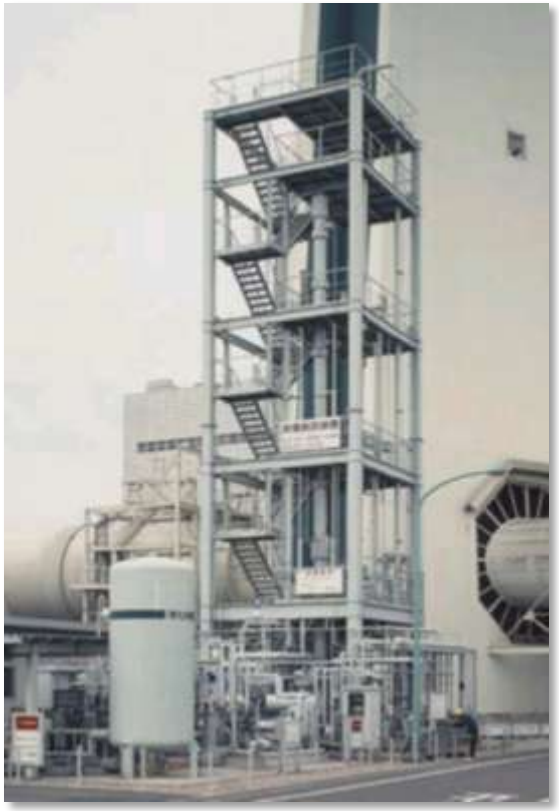
Solvent screening & Pilot test in Nanko Power Plant

- ✓ Potential solvents were selected in terms of reaction speed, VLE, corrosiveness, thermal stability, Oxidative stability, Volatility, and manufacturing cost.
- ✓ A few solvent and optimized combination of component were tested in 2017/2018 campaigns.



Nanko CO_2 Capture Pilot Plant	
Location	Osaka, Japan
Flue gas source	Natural-gas boiler
CO_2 capacity (tonne/day)	2
Tested CO_2 concentration (mol%)	4-20
Design capture ratio (%)	90
Configuration	Flue gas quencher
	Intercooled absorber
	Multipul water wash
	MHI energy saving system

New solvent development

Target: Less solvent consumption, less amine emission and high pressure Regeneration

- ✓ **Thermal stability**
  - Reduce thermal degradation and allow higher stripping T and P, reducing compression work
- ✓ **Oxidative stability**
  - Reduce amine oxidation and HSS formation rate
- ✓ **Volatility**
  - Reduce amine loss from emission and cost of water wash system
- ✓ **Cost**
  - Competitive manufacture cost

Parameters Relative to KS-1™	KS-1™	KS-21™
Volatility	100	50-60
Thermal degradation rate	100	30-50
Oxidation rate	100	70
Heat of absorption	100	85

Summary

Summary

1. **KM CDR Process™** has **World's largest delivery** of CO_2 Capture Plants for over 100 tpd capacity since 1999;
   13 plants under commercial operation including **World's largest CO_2 capture plant** (Petra Nova) and currently 2 under construction

2. **Commercially proven** & used on **Natural gas, Heavy oil, and Coal** for many purpose such as Urea, Methanol, EOR and other general usage.

3. **Reduces CAPEX by 30% using Advanced KM CDR Process™ & New KS-21™ solvent**
   - Updated technology & Lessons learned
   - Reduce Design margin by reflecting actual performance in recent projects
   - Lower amine emissions
   - Expects to offer for new commercial projects in 2019.

Thank you

Further Question
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