Pilot Plant Testing of Piperazine (PZ) with High T Regeneration

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Budget Period 1

$ 1.65 M	Federal Share
$ 0.92 M	Cost Share
$ 2.57 M	Total BP1

Cost share by CO_2 Capture Pilot Plant Project (C2P3)

Objective is to develop PZ with advanced regeneration at 150°C

PZ
- Optimize solvent (8m vs 5m)
- Demonstrate solvent robustness

Regeneration
- Two stage flash (2SF)
- Advanced flash stripper (AFS)

Aerosols
- Formation and control
- Characterization

Phased testing at UT SRP and NCCC to optimize PZ absorption/regeneration

SRP 2011
- 2SF
- 8m PZ

Completed

SRP 2013
- 1SF
- 5m PZ
- Aerosol

Completed

SRP 2015
- AFS
- 5 vs 8m
- Aerosol

Completed

NCCC 2017
- AFS
- 5m PZ
- Aerosol

Pending NETL Approval

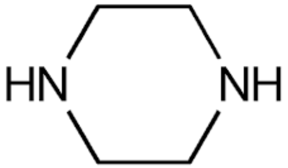
0.1 MW
CO_2 in air
BP1

0.5 MW
Flue gas
BP2

The Lessons

- 5m PZ is a superior solvent
- AFS minimizes energy use for regeneration
- 5m PZ + AFS decreases cost of CO_2 capture
- Amine aerosols can be measured with FTIR and PDI

5m Piperazine
is a superior solvent



PZ solvent properties

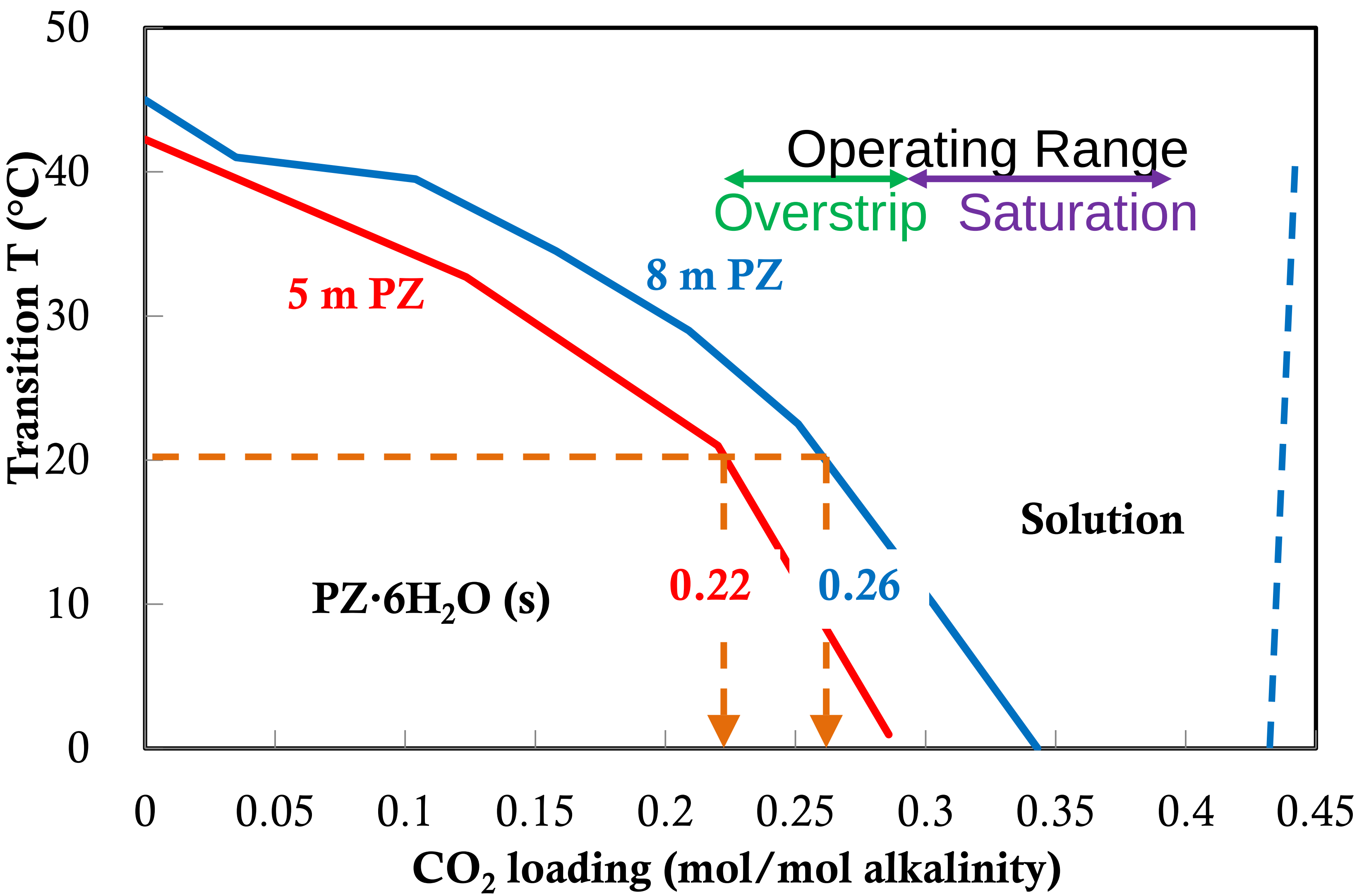
- Fast kinetics
- High capacity
- Low volatility
- Resistant to Degradation
  - Thermal (stable to 150°C)
  - Oxidation (4x more stable than MEA)
  - Nitrosation (MNPZ decomposes at 150°C)
- Solid solubility limits its application

5m PZ: optimizes advantages of PZ

Wider solubility

- Can be used at lower lean loading without solids ppt
- No solids precipitation at rich loading

5m PZ has a wider solubility window



5m PZ: optimizes advantages of PZ

Wider solubility

- Can be used at lower lean loading without solids ppt
- No solids precipitation at rich loading

Faster kinetics

- 33% faster absorption kinetics vs. 8m PZ

Amine	m	$k_g'_{avg}$*1e7	μ	ΔC_μ	T_{max}
		mol/s·Pa·m²	cP	mol/kg	C
PZ	**8**	**8.5**	**11**	**0.84**	**163**
	5	**11.3**	**4**	**0.81**	**163**

5m PZ improved CO_2 removal at SRP

	Run	Solvent	Solvent Rate GPM	Gas Rate ACFM	Titration LLDG mol CO_2/mol alk	Measured Removal
Test 1	**9**	5 m	14	500	0.24	80%
	14	8 m				75%
Test 2	**8**	5 m	14	350	0.24	96%
	15	8 m				93%
Test 3	**3**	5 m	10.2	350	0.22	94%
	16	8 m			0.23	91%

5m PZ: optimizes advantages of PZ

Wider solubility

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- No solids precipitation at rich loading

Faster kinetics

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Lower viscosity

- Higher heat transfer coefficients for cross exchangers, trim cooler, absorber intercooler

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		mol/s·Pa·m²	cP	mol/kg	C
PZ	**8**	**8.5**	**11**	**0.84**	**163**
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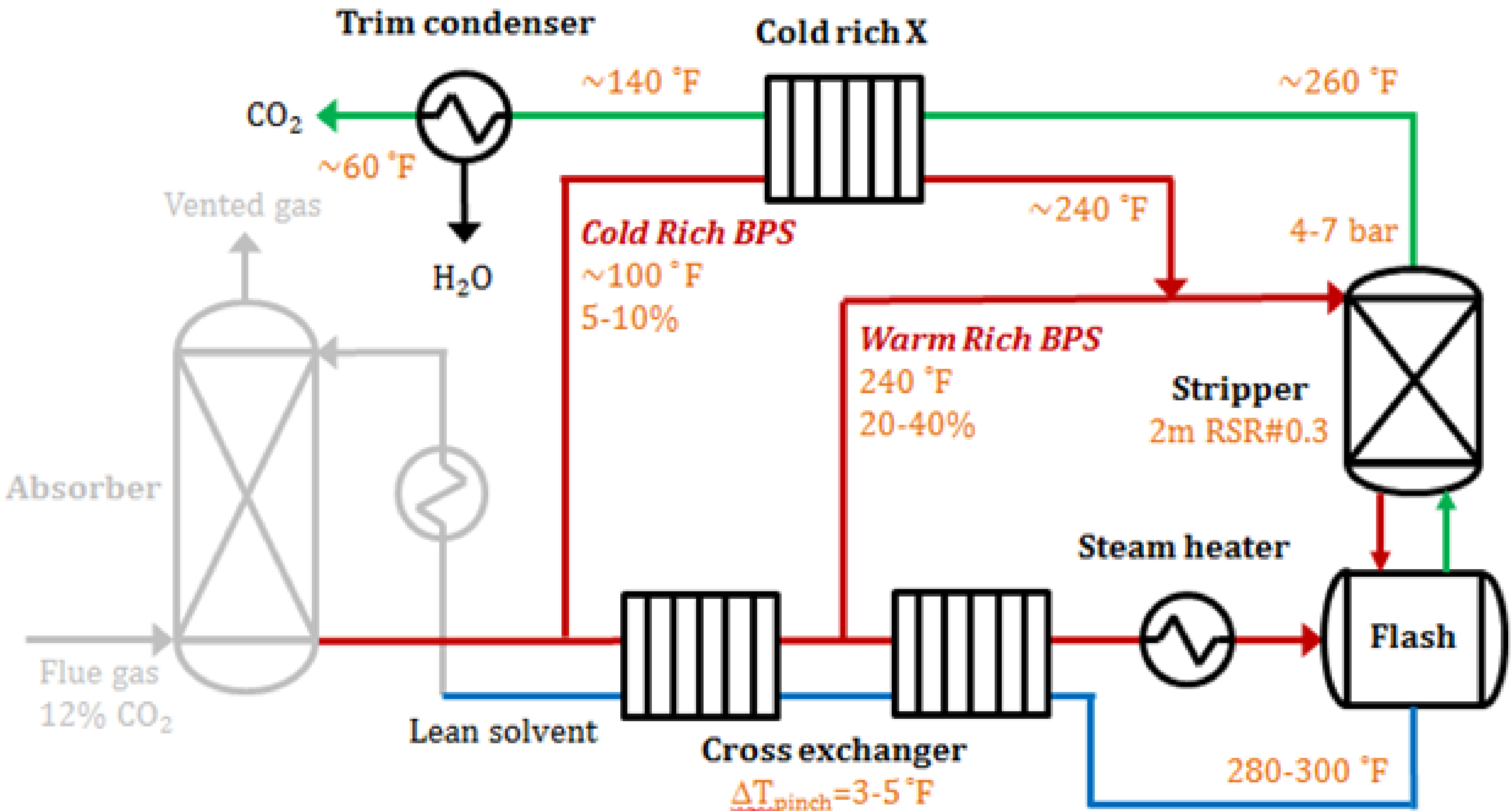
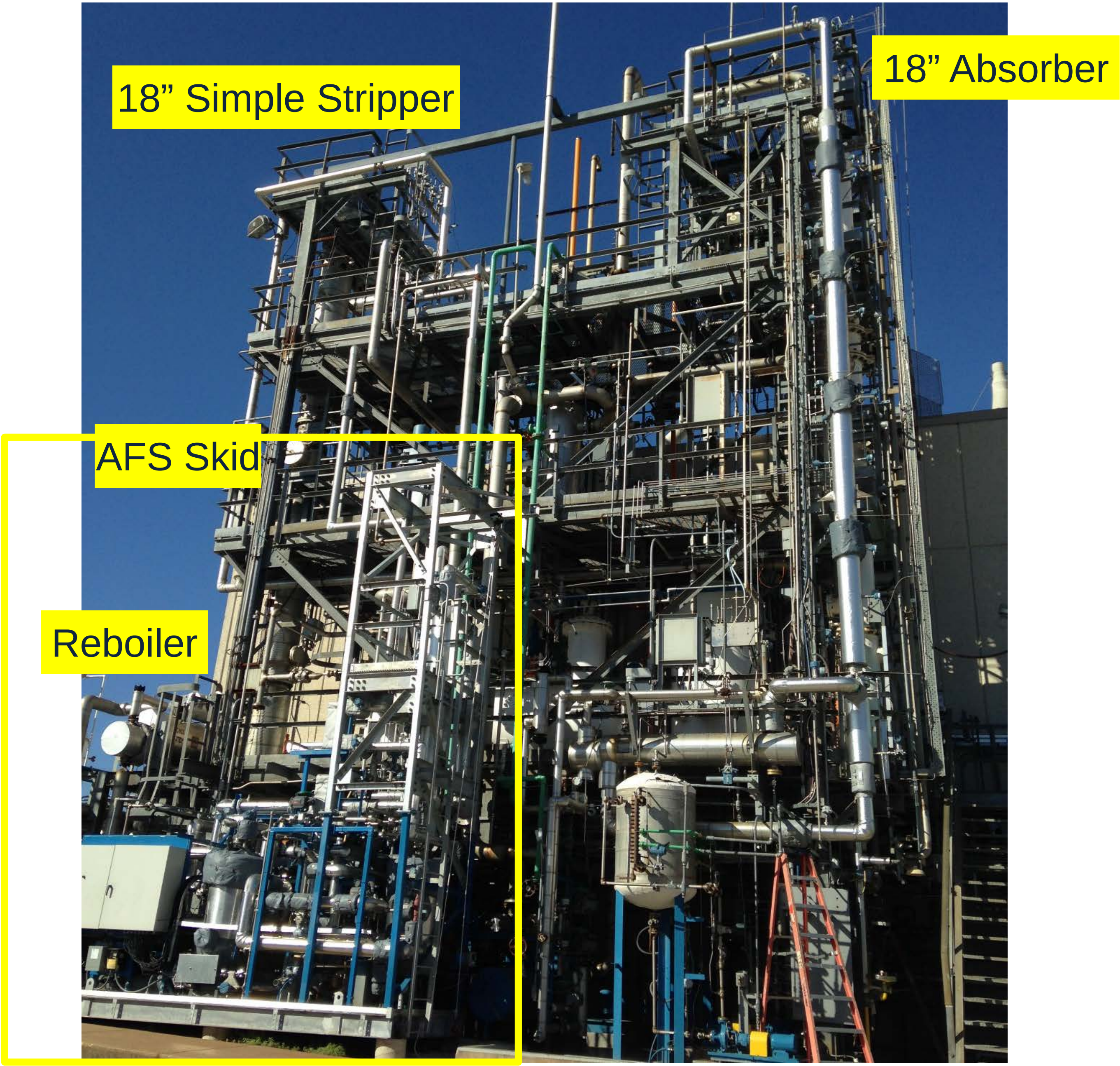
5m PZ improved cross exchanger performance and reduced heat duty

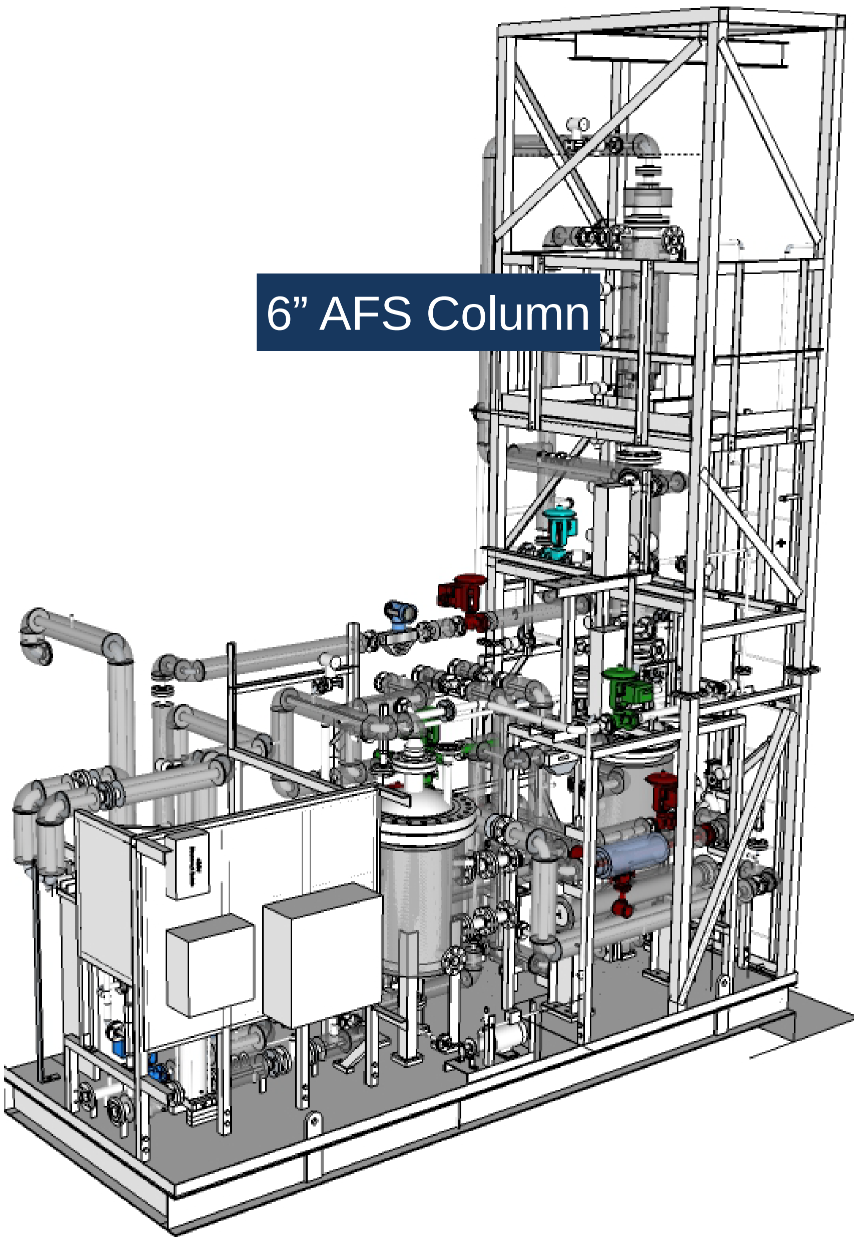
	Comparison 1 (293°F 0.24 ldg)		Comparison 2 (293°F 0.24 ldg)	
Run	8	15	9	14
PZ concentration (m)	5	8	5	8
Solvent capacity (lb CO_2/lb solution)	0.036	0.037	0.041	0.042
Total BPS ratio	25%	24%	26%	24%
Heat duty (GJ/tonne CO_2)	2.36	2.51	2.21	2.41
Cross X cold side ΔT (°F)	11.7	15.2	11.5	15.7

The Advanced Flash Stripper (AFS)
minimizes energy use

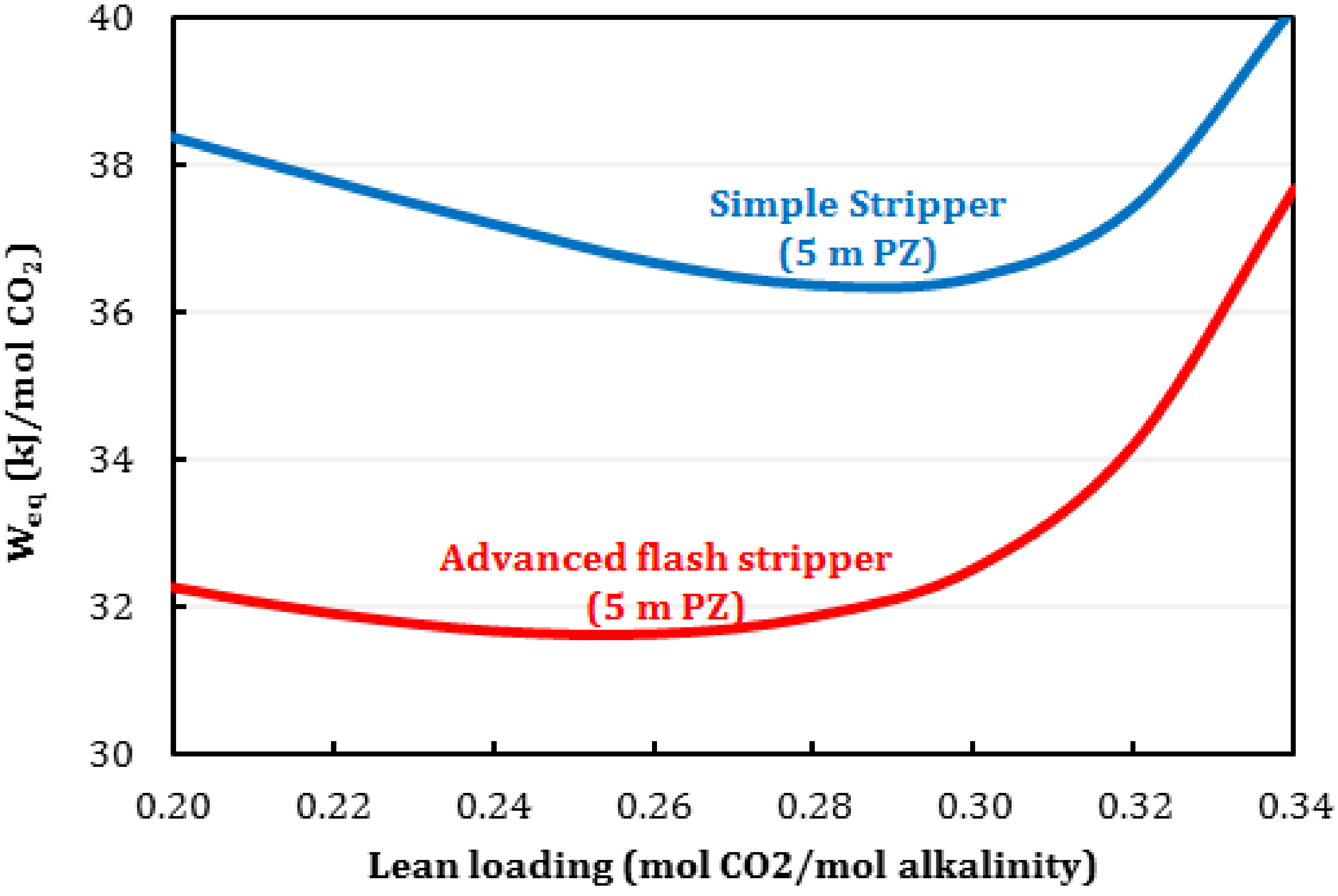
Advanced Flash Stripper with 5m PZ



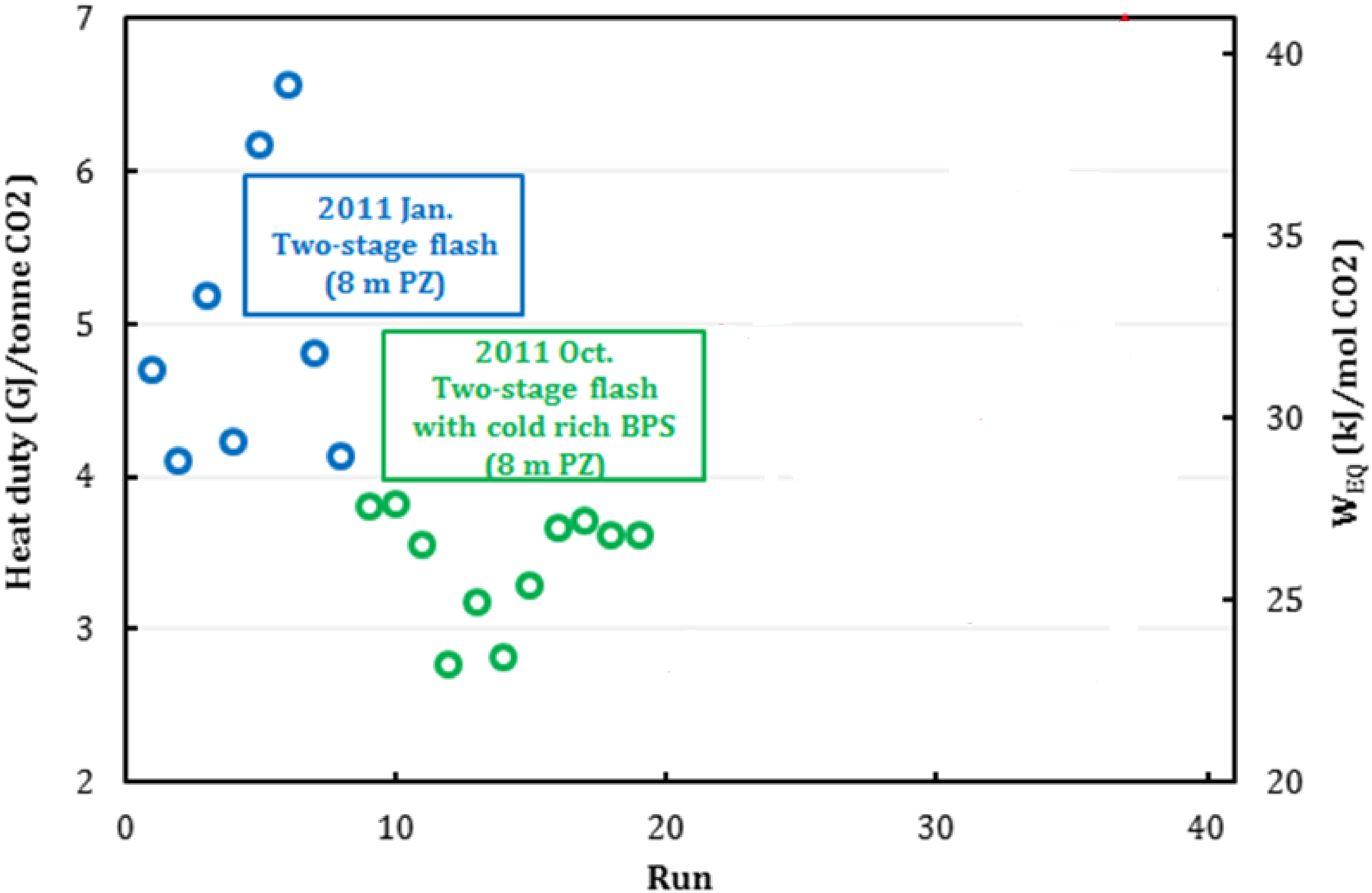

18” Simple Stripper
18” Absorber
AFS Skid
Reboiler


6” AFS Column

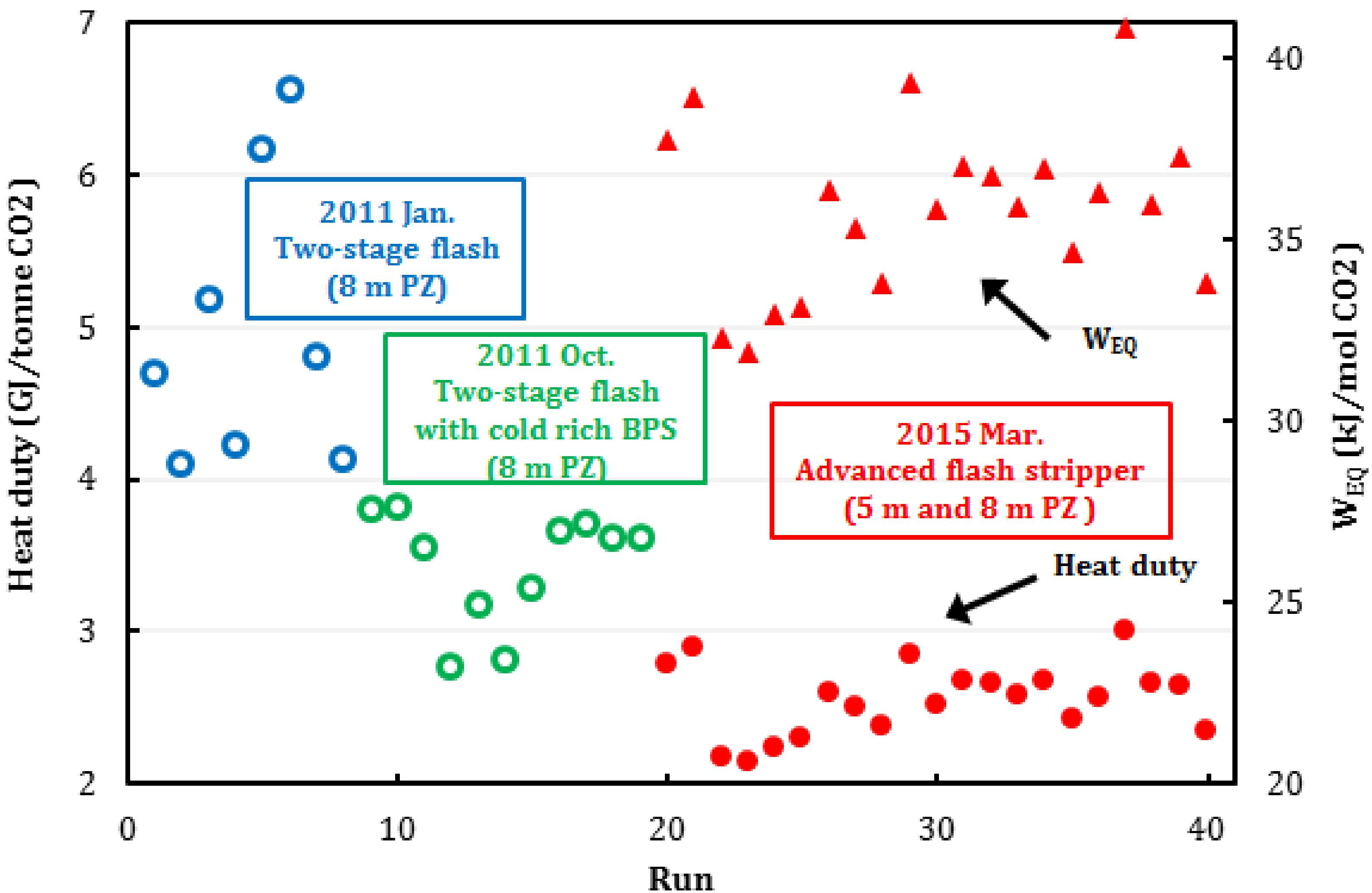
AFS has lower W_{eq} than SS



Cold-rich bypass reduced energy requirement of 2SF



AFS reduced energy requirement by 25%



5m PZ + AFS

decreases cost of CO_2 capture

5m PZ/AFS has lowest costs of configurations modeled by UT

- PZ/AFS = $39.03/tonne (no TS&M)
- Econamine = $56.47/ton (no TS&M)

Amine Aerosols can be measured by FTIR and Phase Doppler Interferometer (PDI)

Amine aerosols cause high amine emissions

Nucleation sites in flue gas

- SO_3/H_2SO_4
- Submicron fly ash
- SO_2/amine

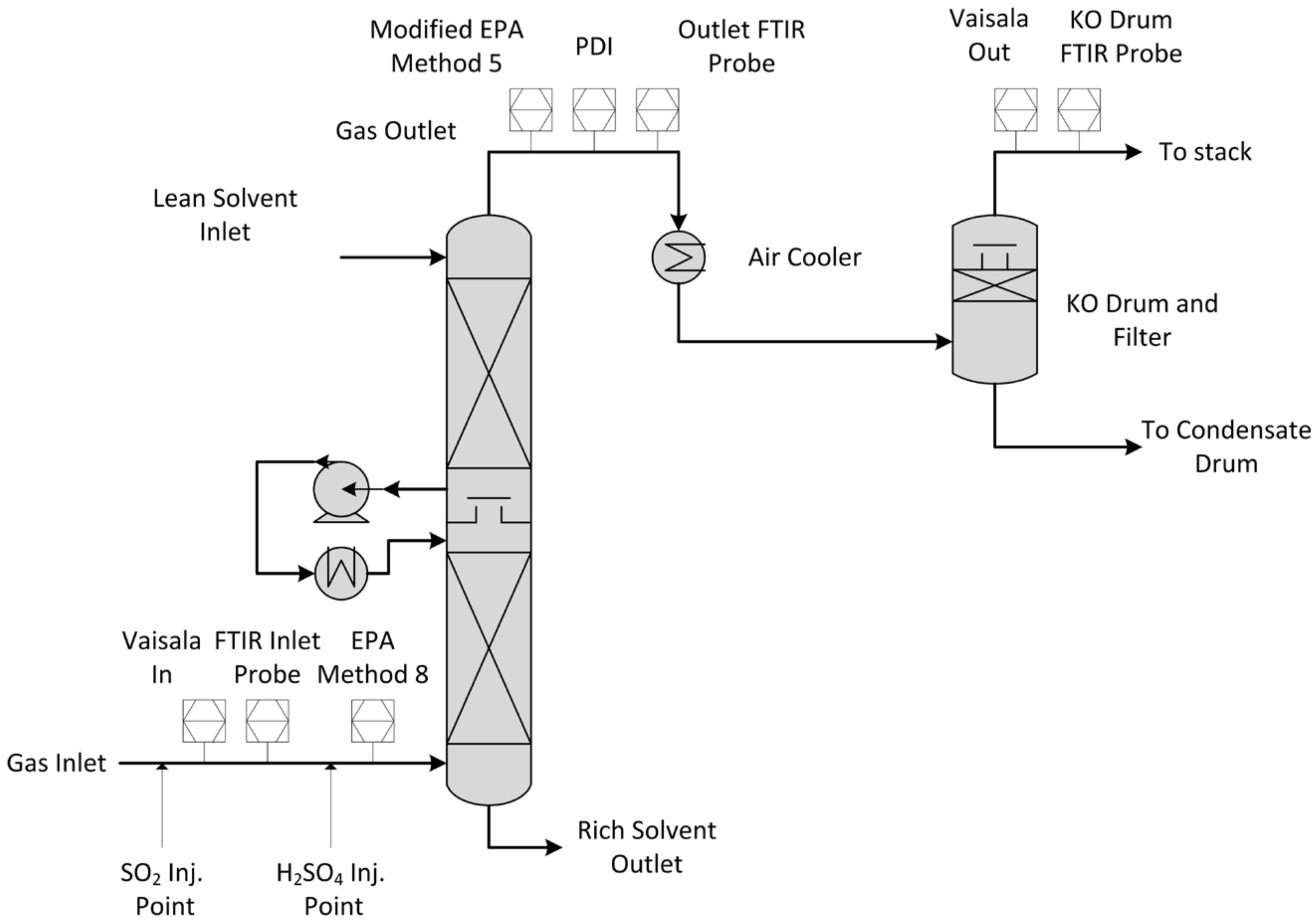
+ Amine condensation

- Amine/CO_2/H_2O from solvent to aerosol

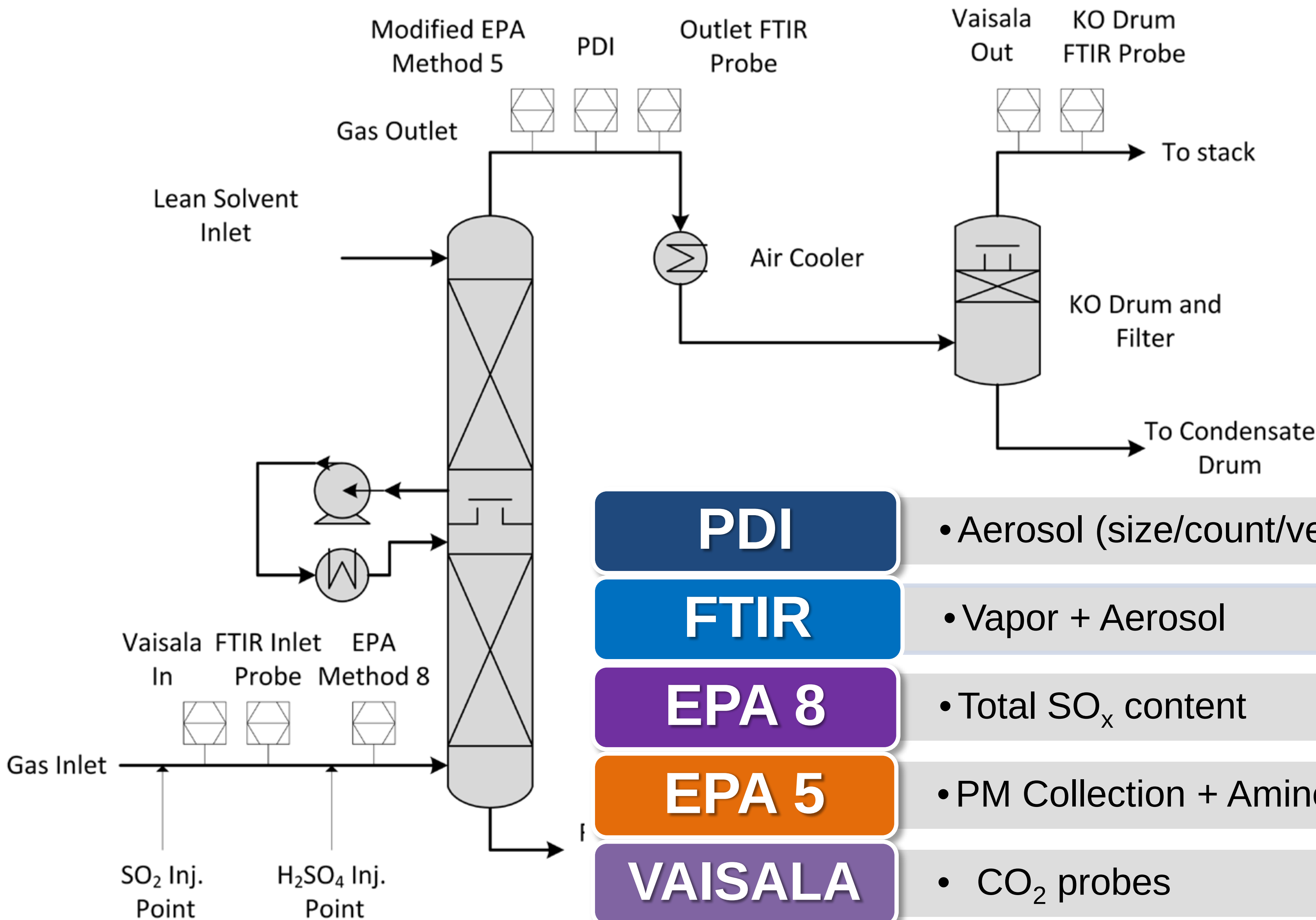
+ Poor collection of small drops in water wash

= Unacceptable amine emissions

PDI, FTIR measurements at SRP

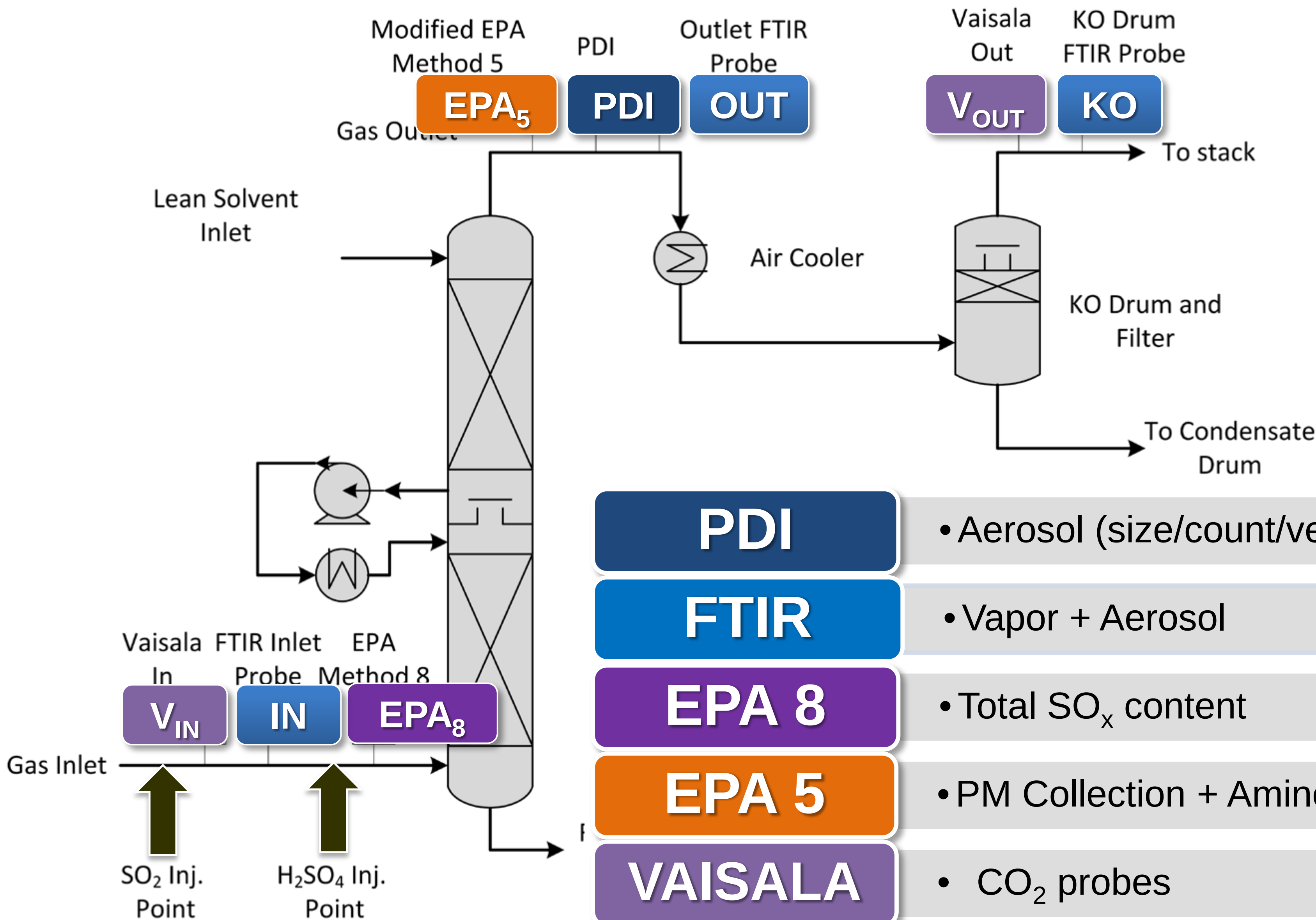


PDI, FTIR measurements at SRP



PDI	• Aerosol (size/count/velocity)
FTIR	• Vapor + Aerosol
EPA 8	• Total SO_x content
EPA 5	• PM Collection + Amines
VAISALA	• CO_2 probes

PDI, FTIR measurements at SRP



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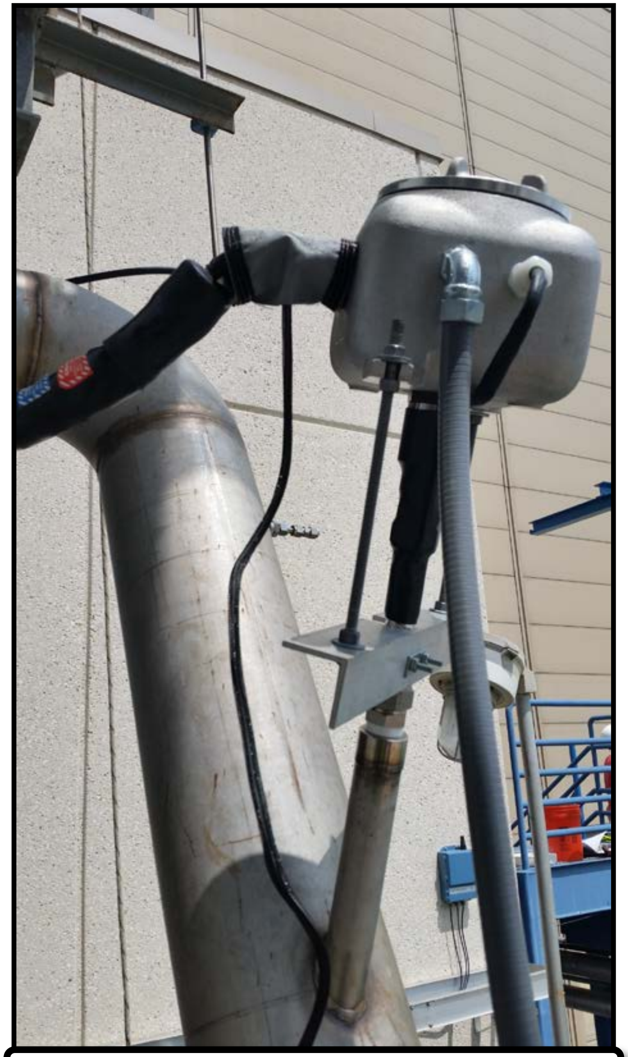
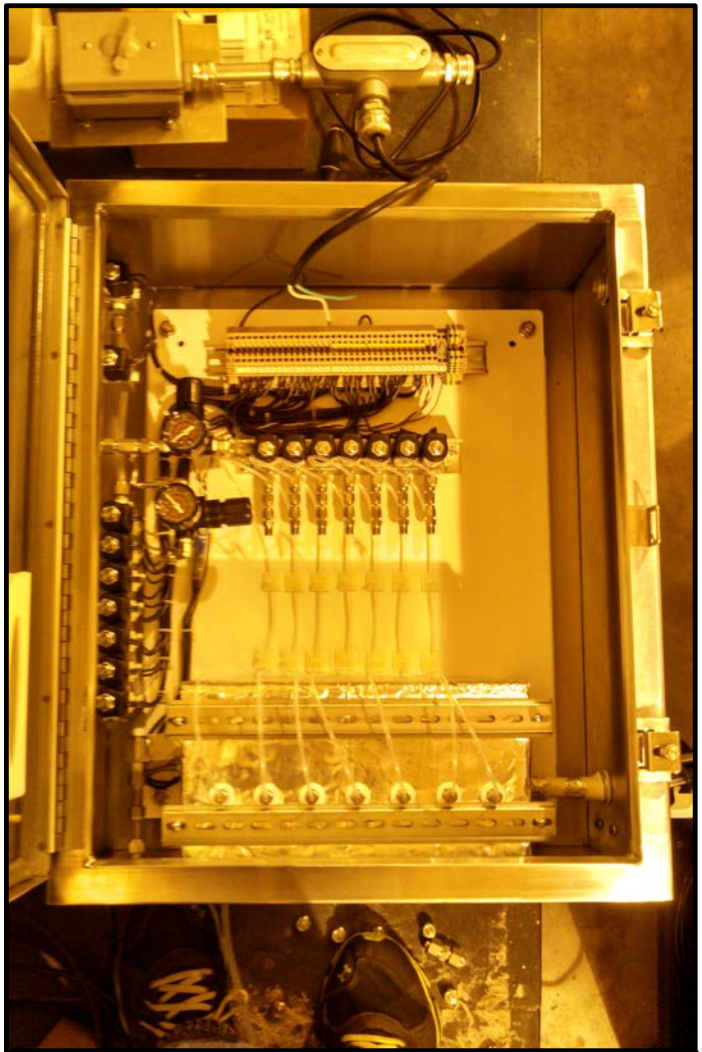
FTIR Sampling



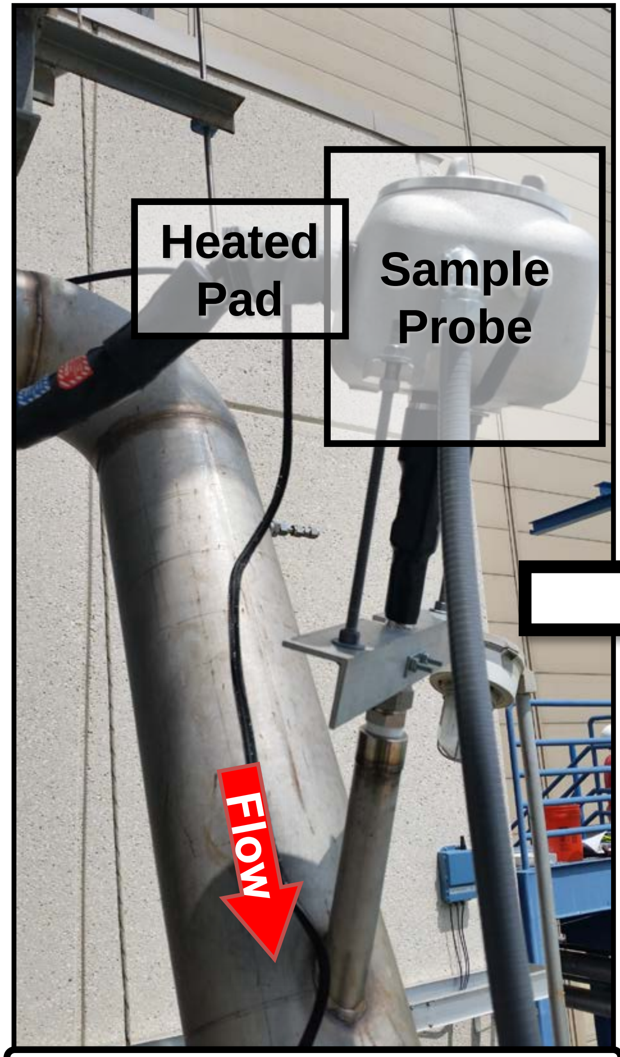
Field Sampling



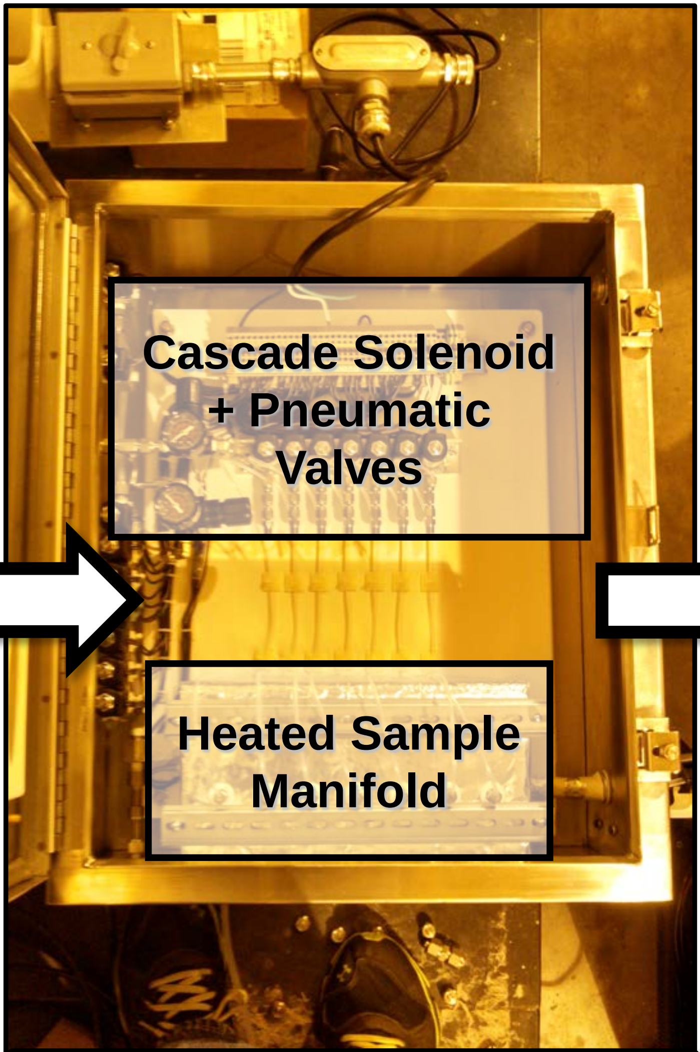
Select Sample Point

FTIR Analysis

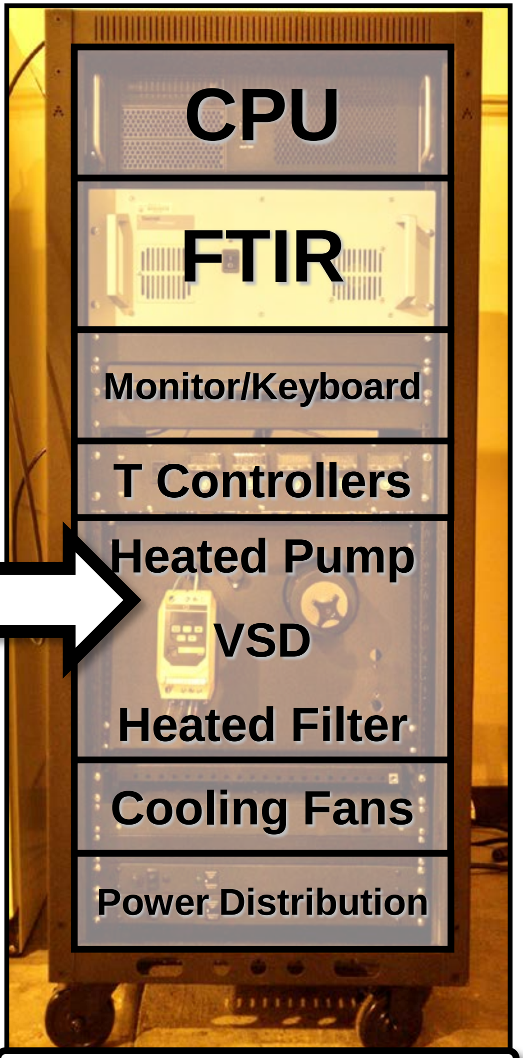
FTIR Sampling



Field Sampling

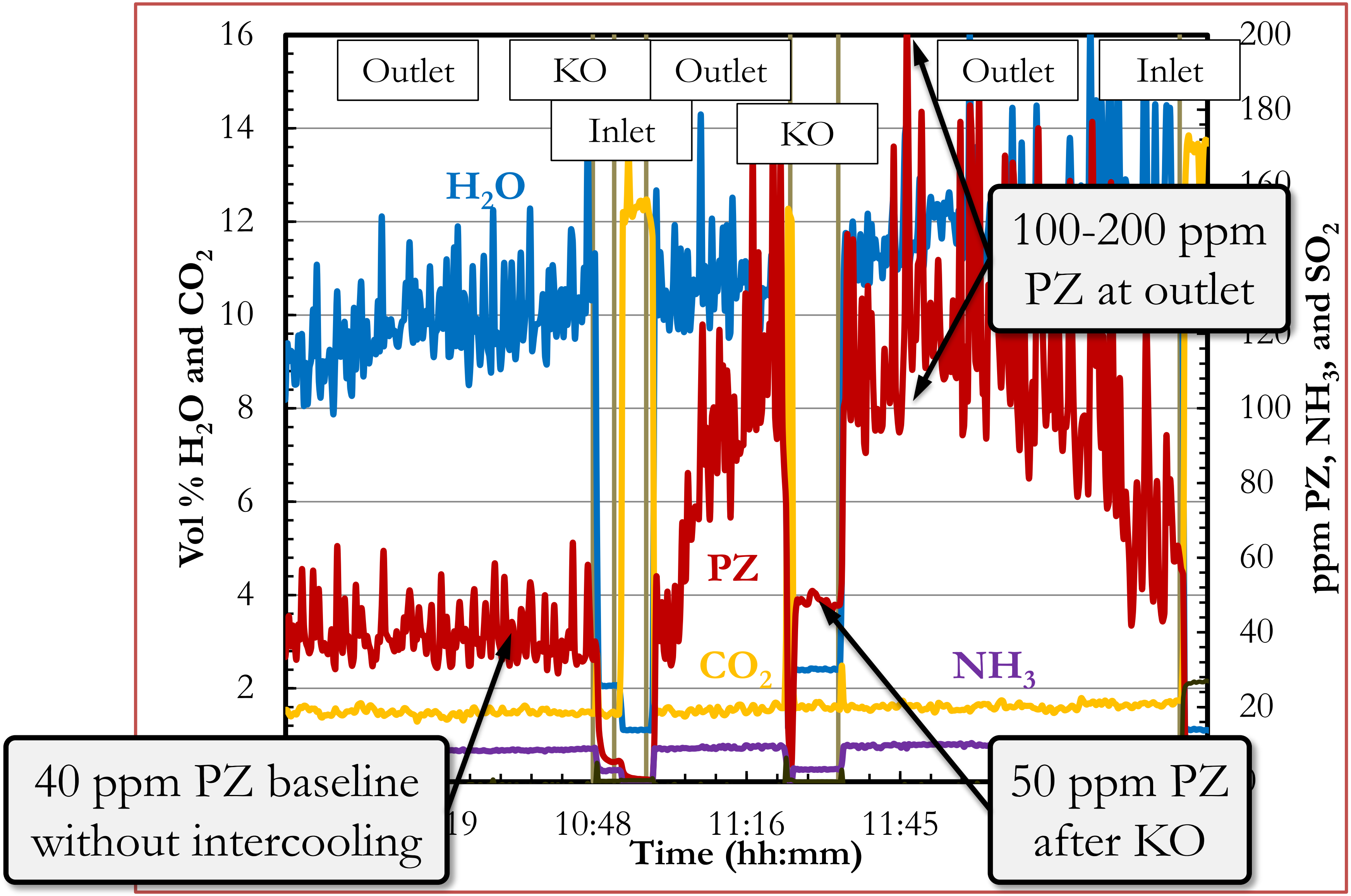


Select Sample Point



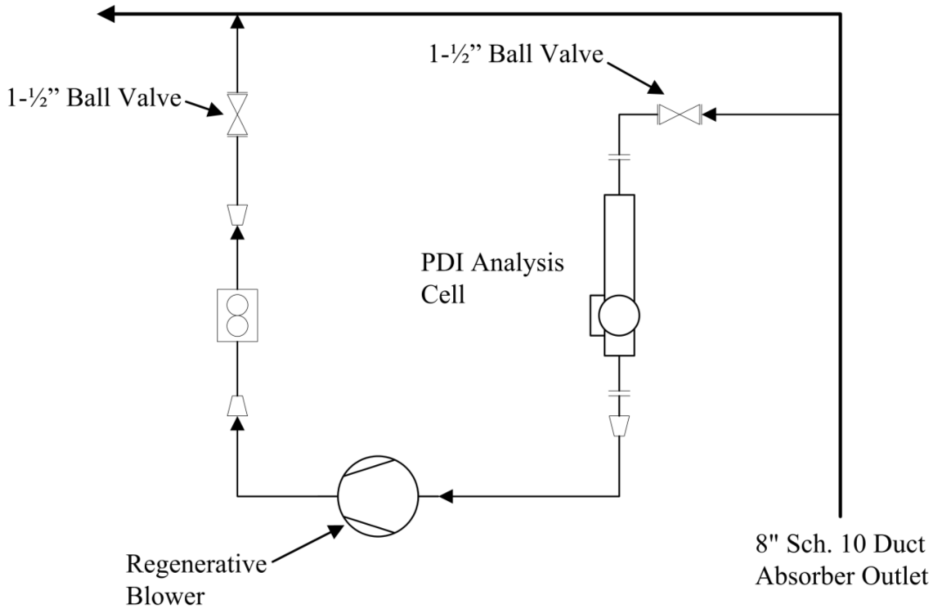
FTIR Analysis

PZ emissions increase with 10 ppm H_2SO_4

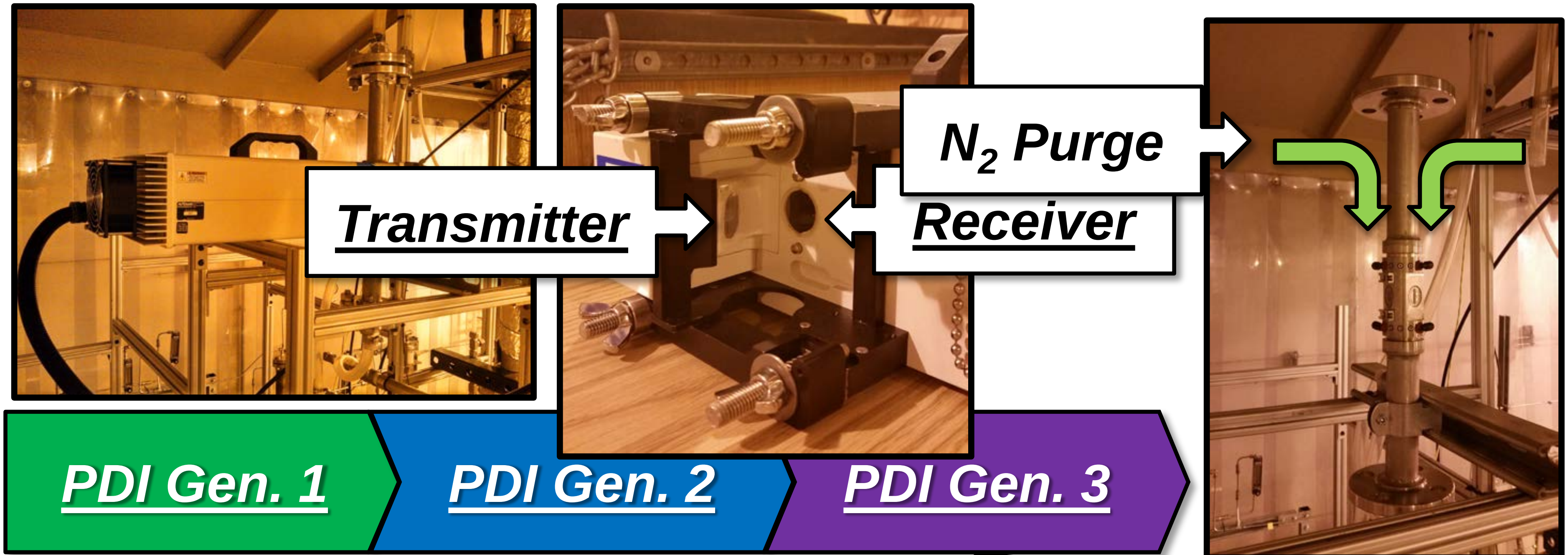


PDI with bypass sampling provided high quality aerosol measurements

- In-situ analysis for aqueous aerosols
- Measure 0.1 – 10 µm at high (10^6 part/cm^3) concentrations
- Eliminate extractive sampling errors
  - Sampling: isokinetic
  - Dilution: concentration limitations, RH
  - State: P/T – Condensation/Evaporation
  - Transmission: impingement, diffusion, settling, deposition



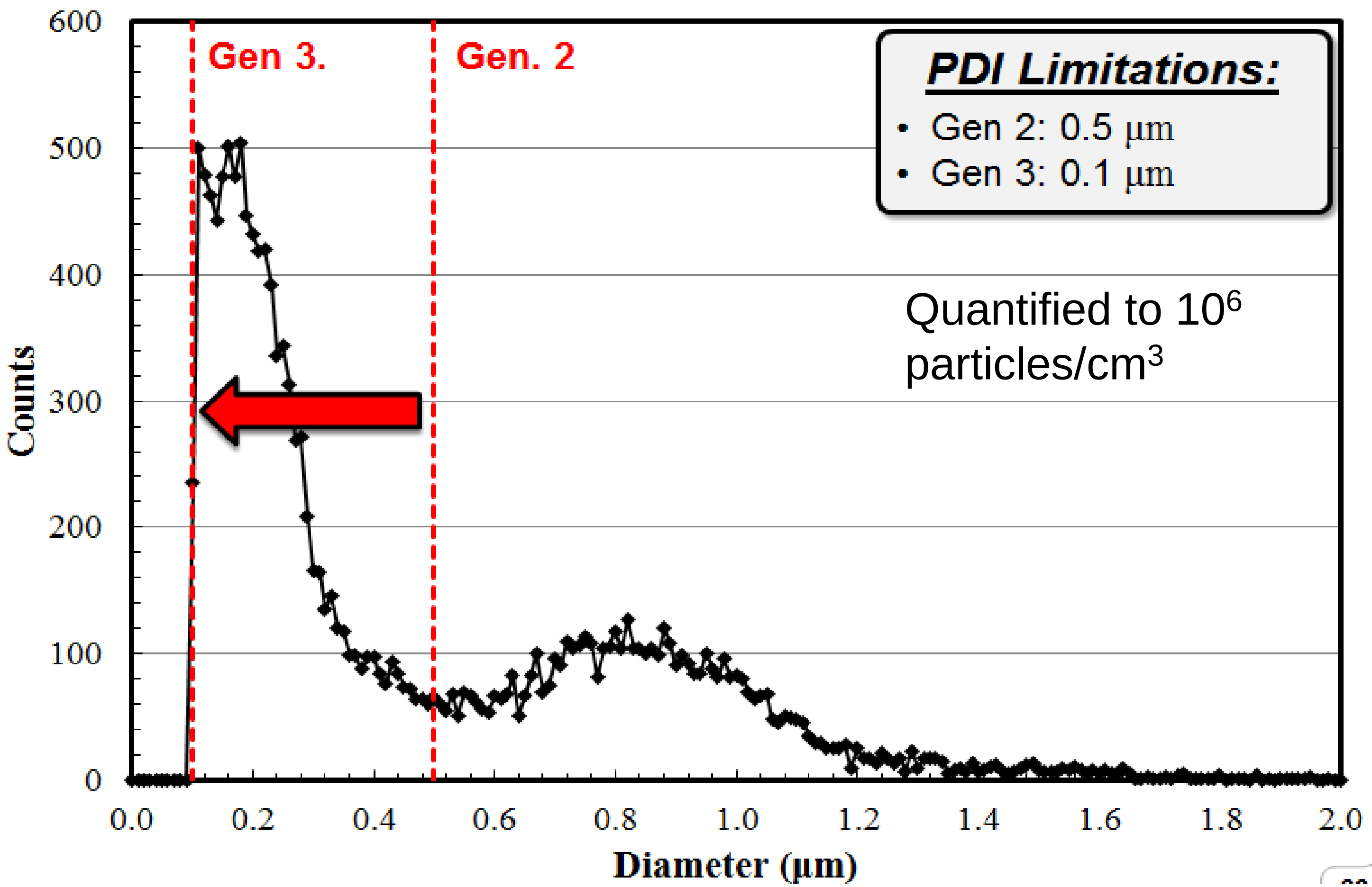
PDI Development



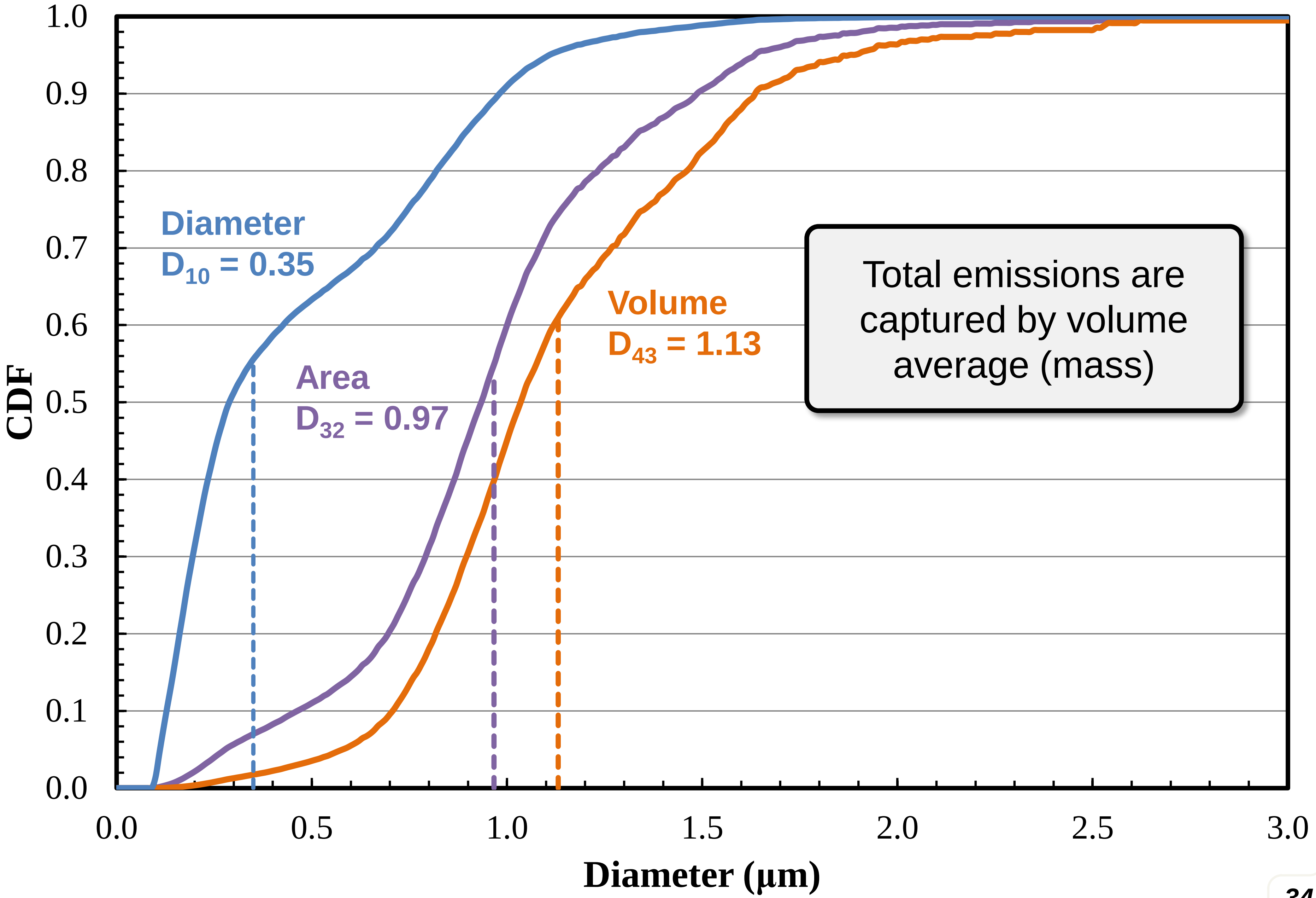
PDI Gen3:

- Custom PDI on 1” Duct (25 mm TX, 39º Cross, 50 →17.8 µm laser)
- 0.1 µm lower detection limit, 10^6 #/cm^3 estimate

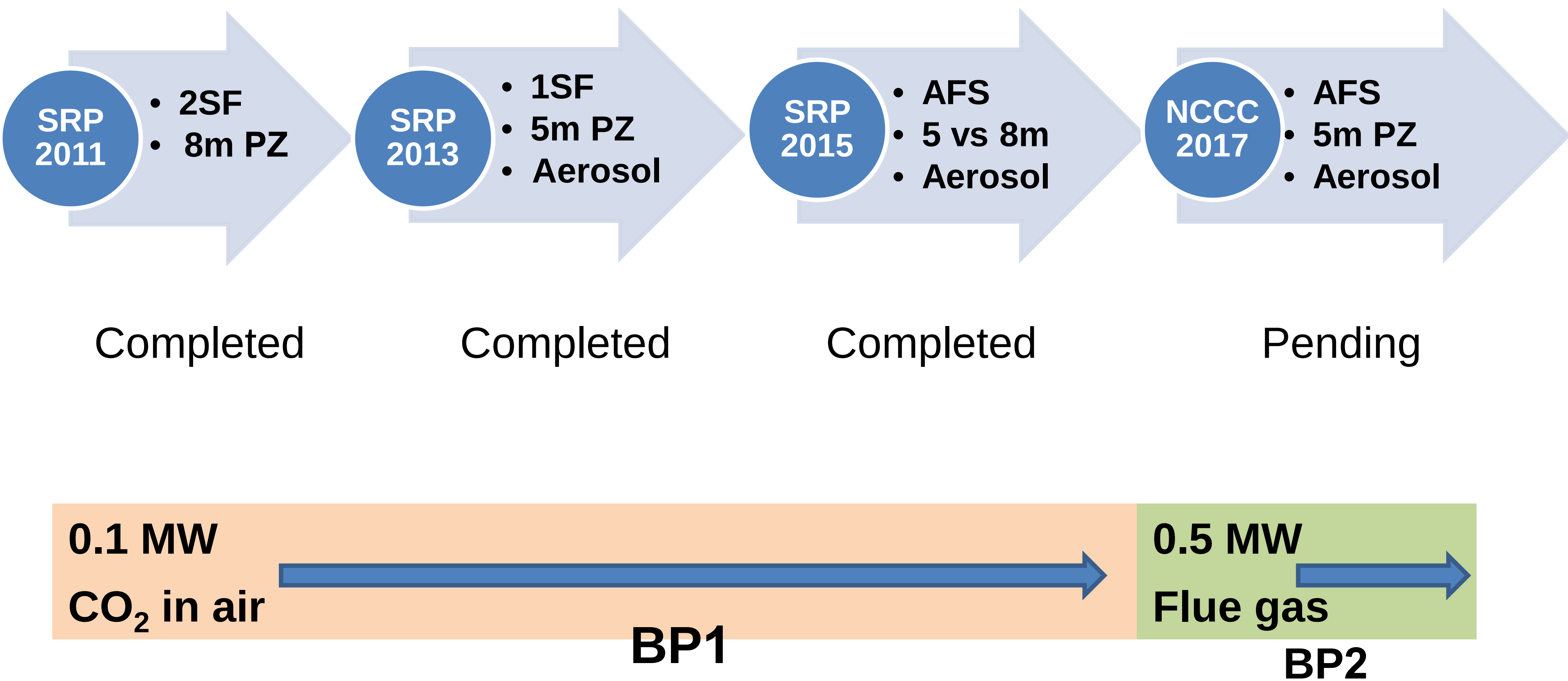
Gen3 PDI detected 0.1 µm particles



Cumulative Distributions (CDF)



BP2 test at NCCC pending NETL approval



BP2 Test Objectives for NCCC

- Demonstrate energy performance & operability at 0.5-MW scale on coal-fired flue gas
  - 5 m PZ
  - AFS
- Confirm economic advantage of 5m PZ + AFS
- Continue study of aerosol formation and measurement

BP2 Schedule

Date	Activity
October 2015	Authorization to begin BP2
January 2016	Process Design Package completed
April 2016	AFS Skid PO issued
November 2016	AFS Skid delivered to NCCC
May – August 2017	NCCC Test Program

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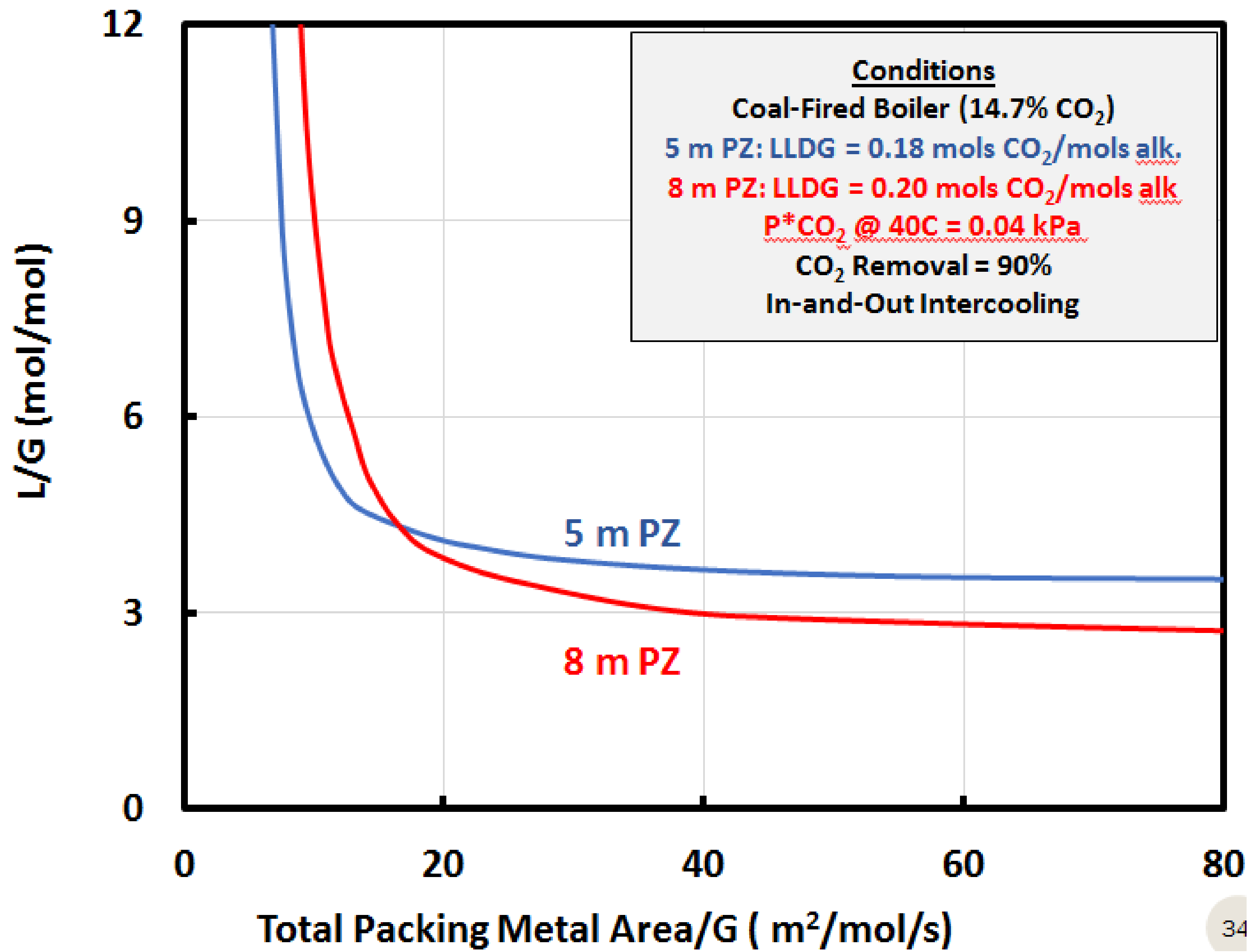
5m PZ has advantage at SRP with packing area is limited



34