Evaluation of Piperazine with Advanced Flash Regeneration for CO_2 Capture from Coal-Fired Flue Gas (FE0005654)

Piperazine (PZ) with Advanced Flash Stripper (AFS)

NCCC pilot Plant Results

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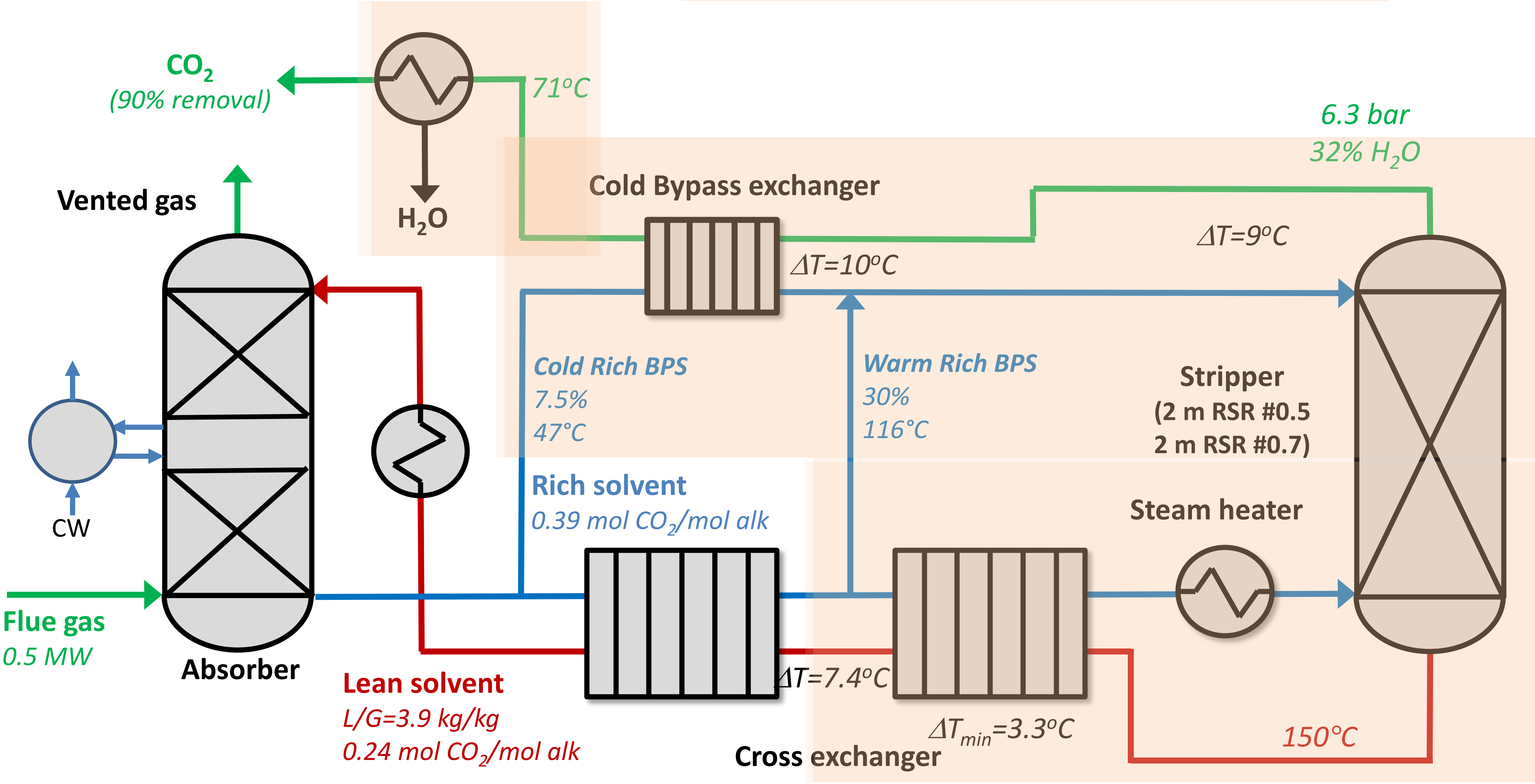
A baseline process for 2G amine scrubbing

- Reliable Design and Operation
- 2.1 GJ/t CO_2 producing CO_2 at 6 bar
- 90-98% removal with 40 ft packing
- Degradation < 0.2 lbs PZ/t CO_2
- 0.5 – 5 ppm PZ emissions at 0 – 4 ppm SO_3
- Carbon steel frequently protected by $FeCO_3$

Demonstrate robustness of PZ & advanced regeneration processes at 0.5 MW

- Team
  - AECOM (Prime Contractor)
  - UT Austin (Technology Provider)
  - Trimeric Corporation (TEA, Process Design)
- Initiation
  - October 1, 2010
- Total Funding Agreement
  - DOE-NETL: $5.1M
  - Cost Share (C2P3): $1.4M
- Target:
  - 90% capture with significant progress to less than 35% increase in COE

Advanced Flash Stripper: New Equipment on Skid



Objectives for 2000 hrs in the PSTU at NCCC

Start-up

- Water test
- Solvent loading
- Operational development

12/12/17
2/22/18

Parametric

AFS Factorial

- Absorber Factorial

600 hrs
2/23
4/12

Simple Stripper

Match best AFS

Compare

250 hrs
4/18
6/4

Long-term

- Reliability
- Performance
- Degradation
- Aerosol

1100 hrs
6/5
8/15

6+ host plant outages of days to weeks

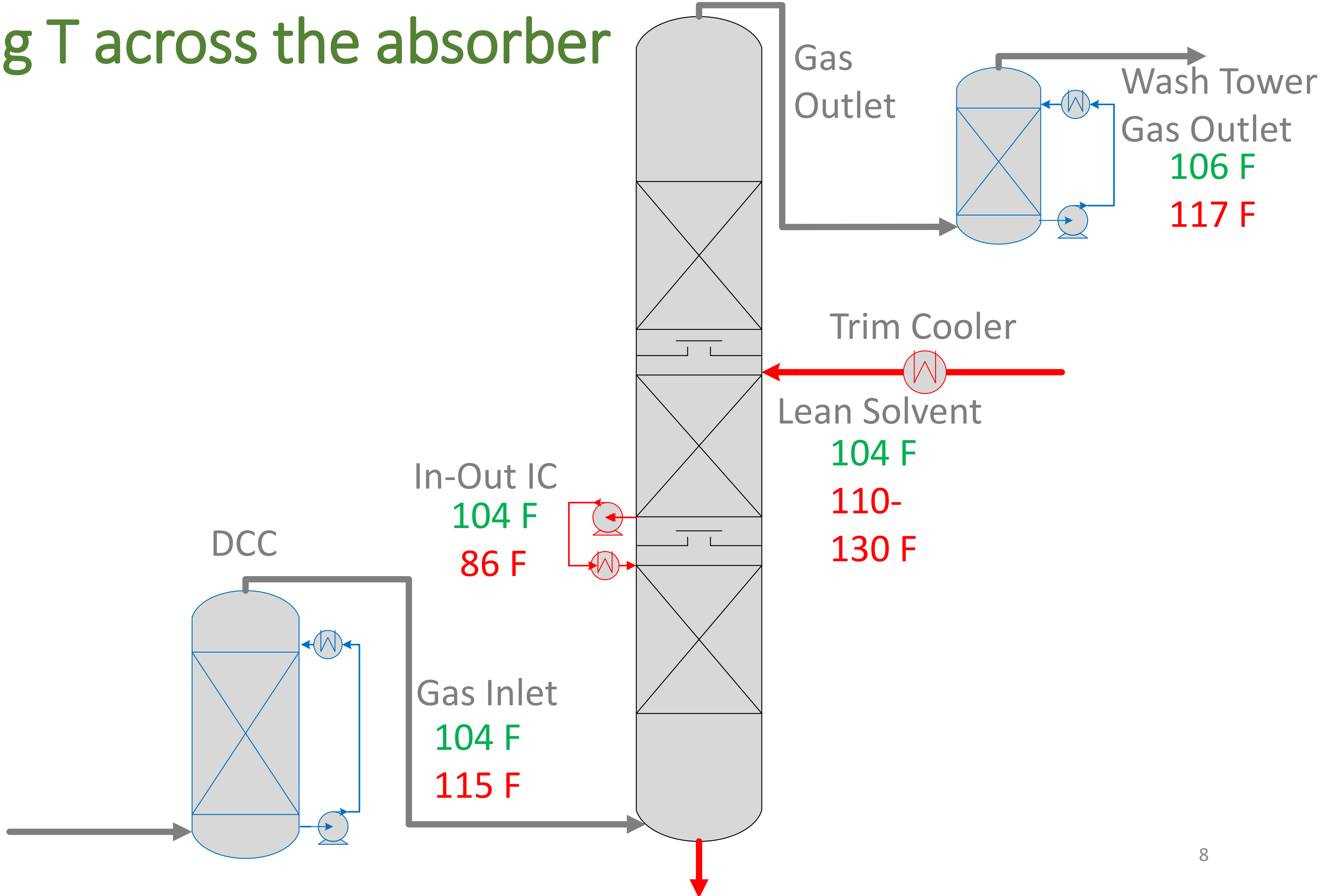
NCCC Operations

PZ Solids Successfully managed
Reliable operation
Seasonal T managed

PZ solids successfully managed

- PZ delivered as 68% solid in mini-ISO container
  - Melted and loaded with CO_2 in circulating hot water
- Numerous boiler shutdowns without PZ precipitation
  - Solvent gravity drained to rich storage
- Plugged CO_2 product flow meter
  - Once during AFS stripper flooding
    - cleaned manually offline
  - Similar plugging with simple stripper (no reflux)

Controlling T across the absorber



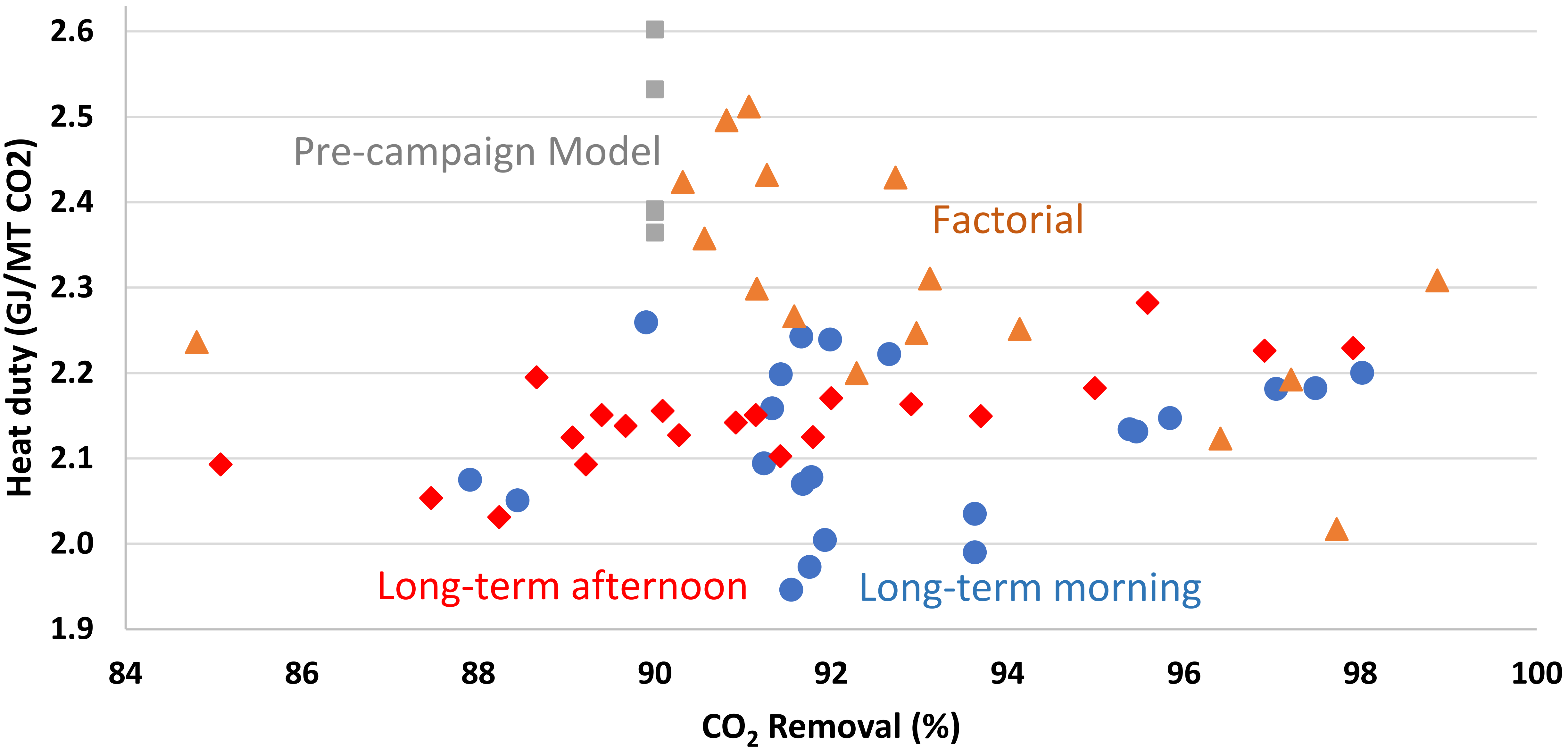
2.1 GJ/t CO_2
150°C Stripper producing CO_2 at 6 bar

90-98% removal
40 ft packing, 0.5 – 0.62 MW gas

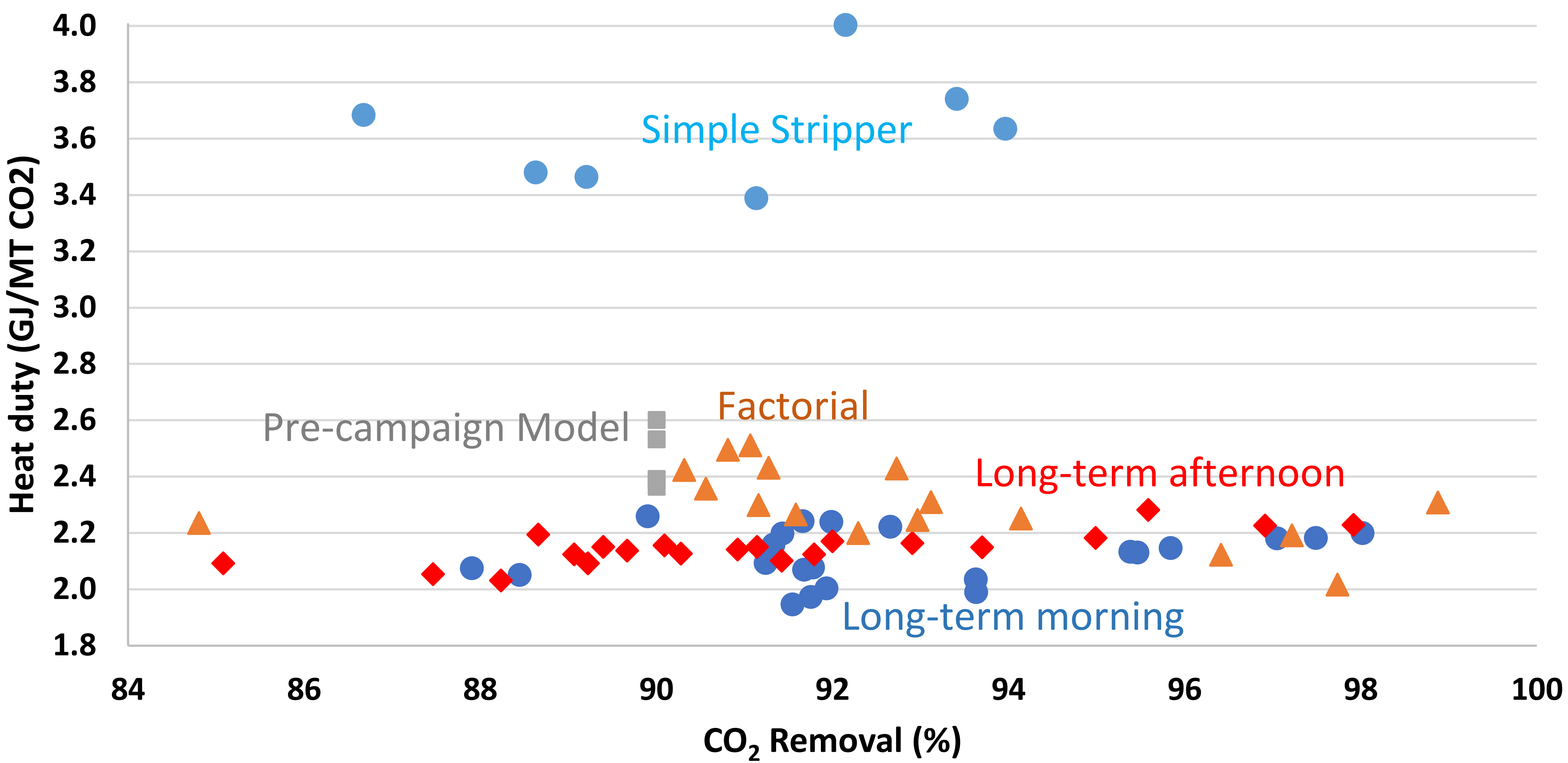
More in the next presentation

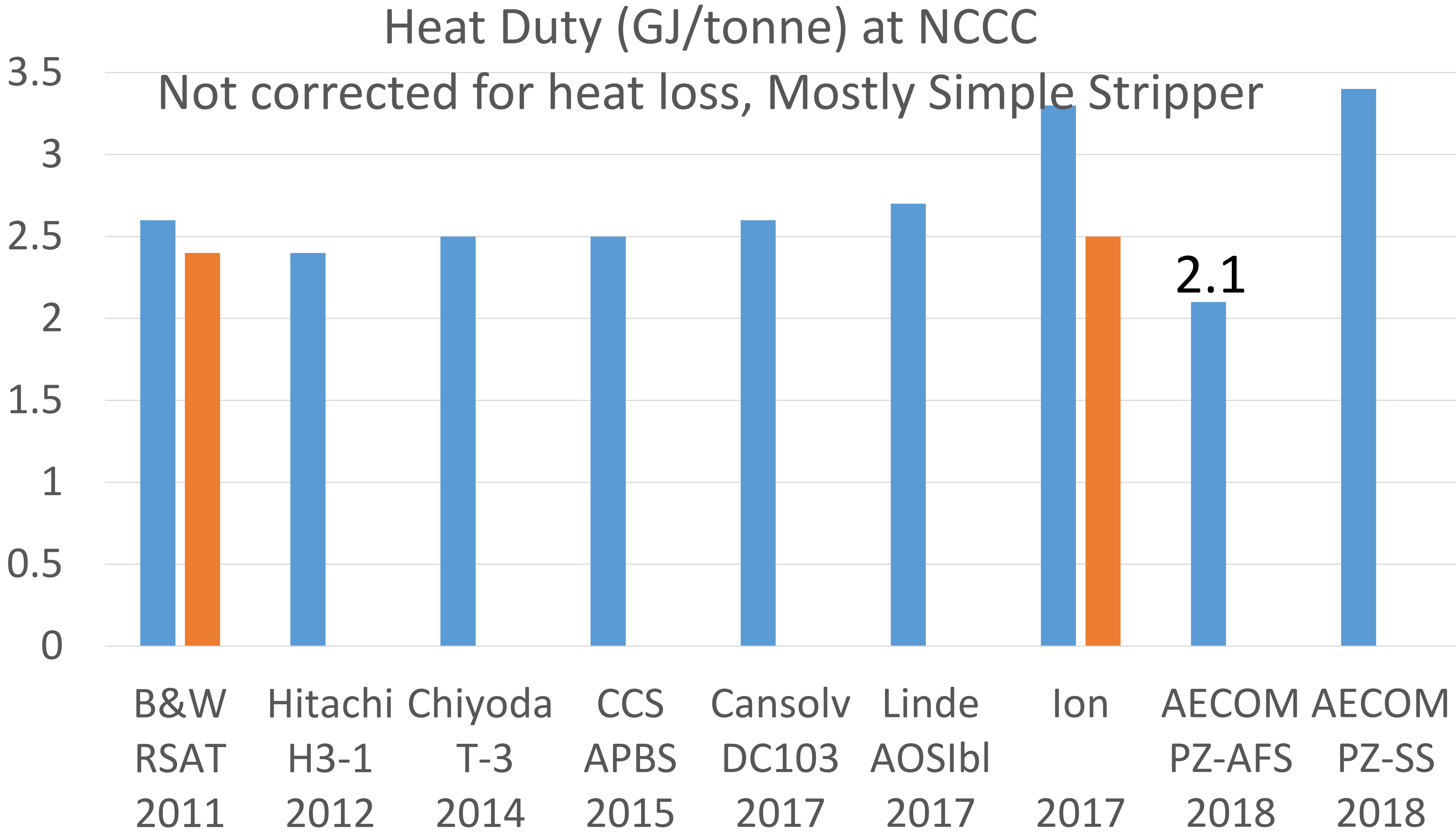
Energy Use of 5 m PZ with Advanced Flash Stripper

No correction for heat loss



Simple Stripper requires 50% more heat





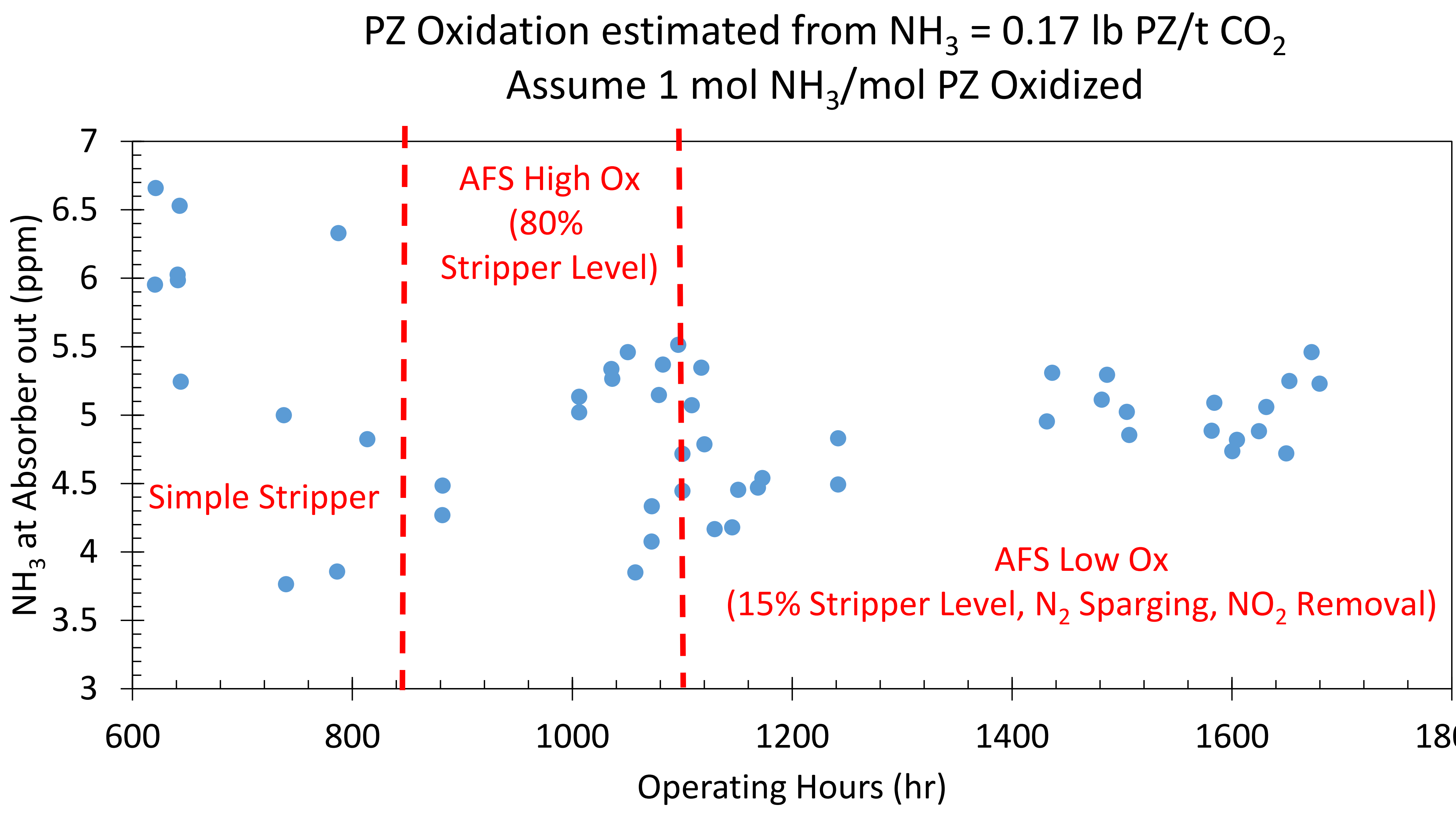
Heat Duty (GJ/tonne) at NCCC
Not corrected for heat loss, Mostly Simple Stripper
3.5
3
2.5
2
1.5
1
0.5
0
2.1
B&W RSAT 2011
Hitachi H3-1 2012
Chiyoda T-3 2014
CCS APBS 2015
Cansolv DC103 2017
Linde AOSIbl 2017
Ion 2017
AECOM PZ-AFS 2018
AECOM PZ-SS 2018

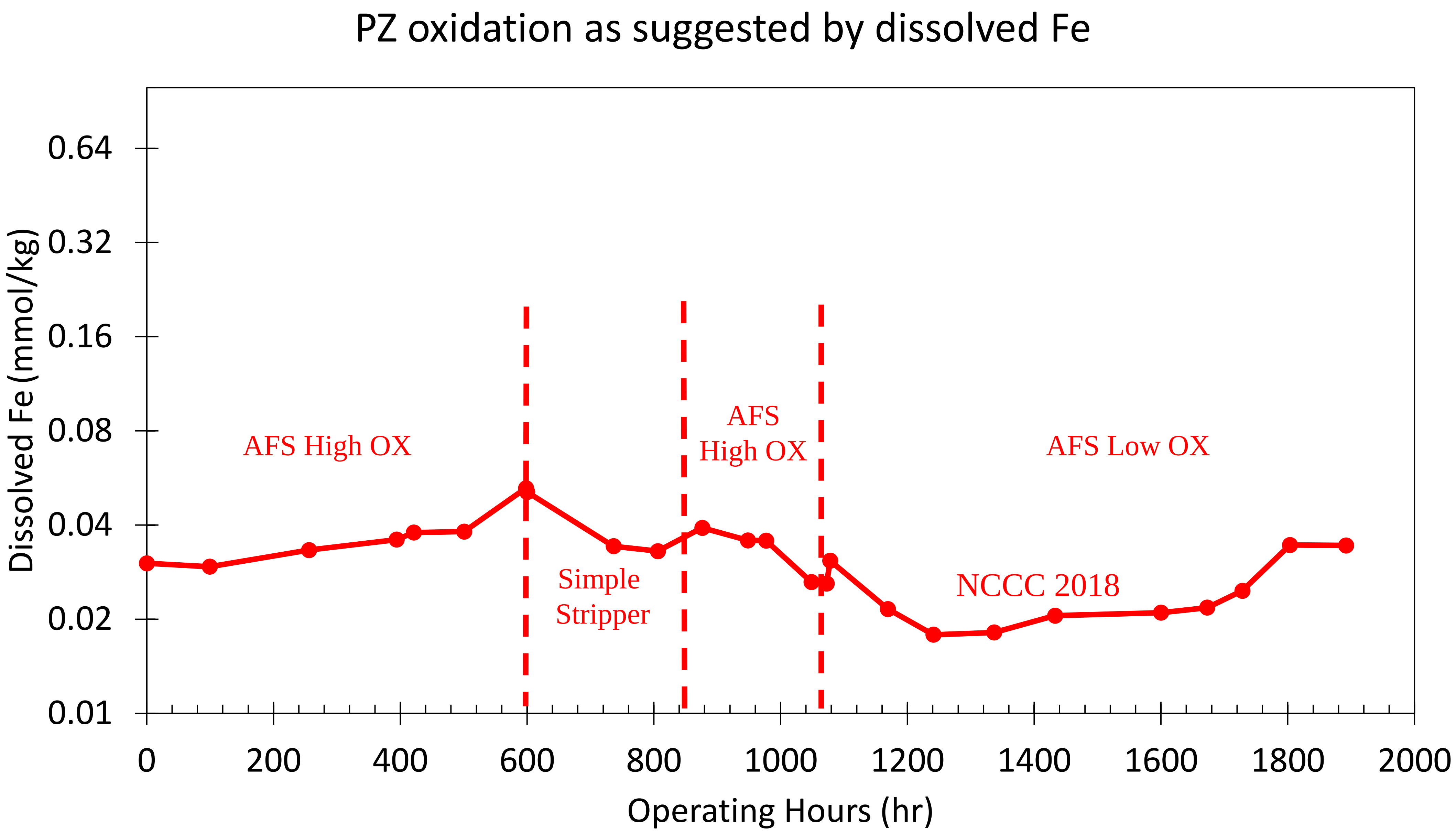
Oxidation by NH_3< 0.17 lb PZ/t CO_2

Total Formate: SRP < NCCC 2018 << Tarong, PP2

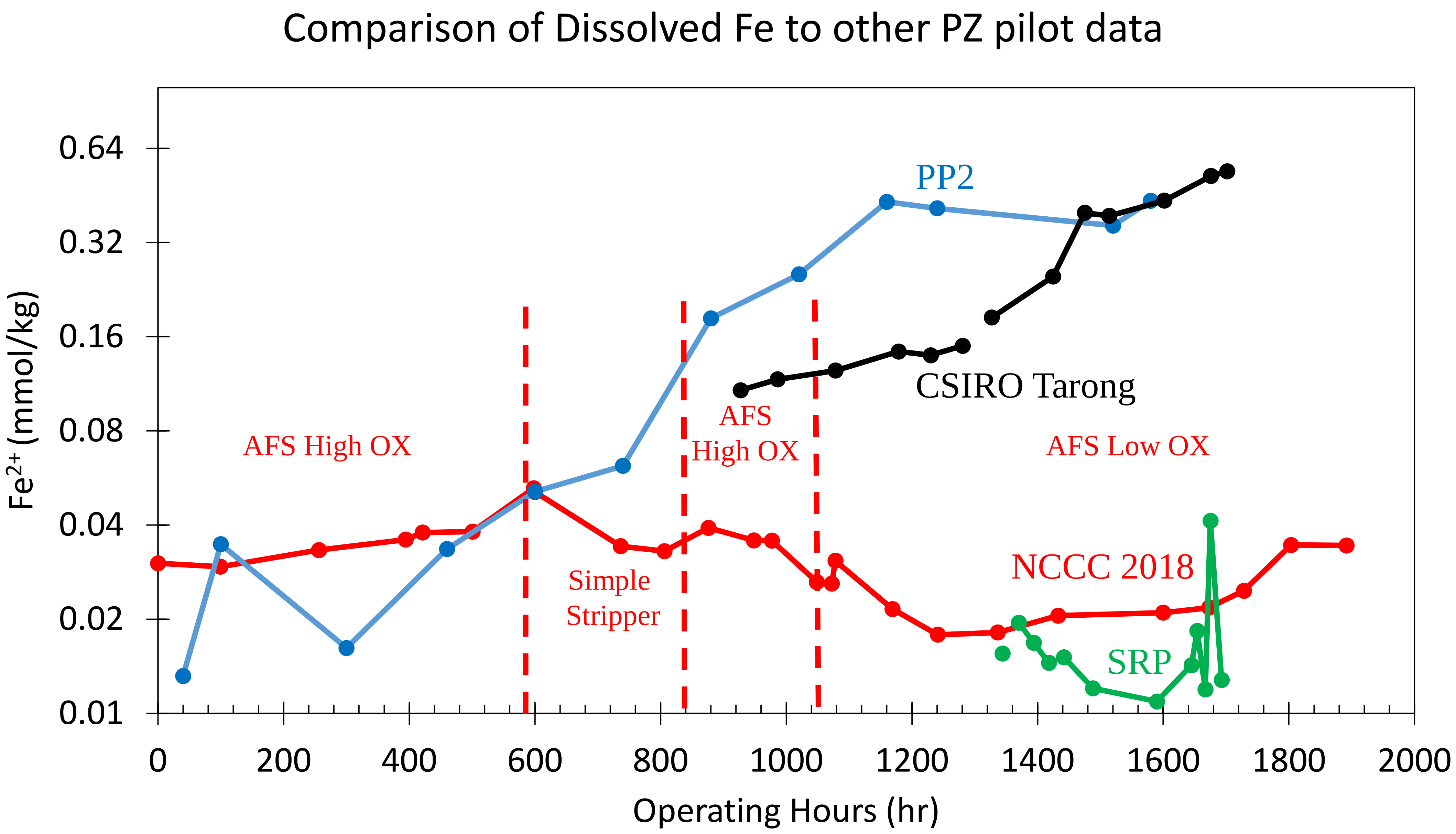
Oxidation Management

- Stripper sump residence time - Fe^{+3} mechanism
  - 80% level – first 6 weeks
  - 15% level – second 6 wks
  - 7% level – impacts energy performance
- Dissolved Oxygen
  - Warm rich bypass residence time at 250°F
  - Flashing in hot exchanger to remove O_2
  - Nitrogen sparging in absorber sump - second 6 wks
- NO_2
  - SCR and Bag filter eliminate NO_2
  - Uncertain residual, SCR reliability
  - Thiosulfate added to prescrubber - second 6 wks

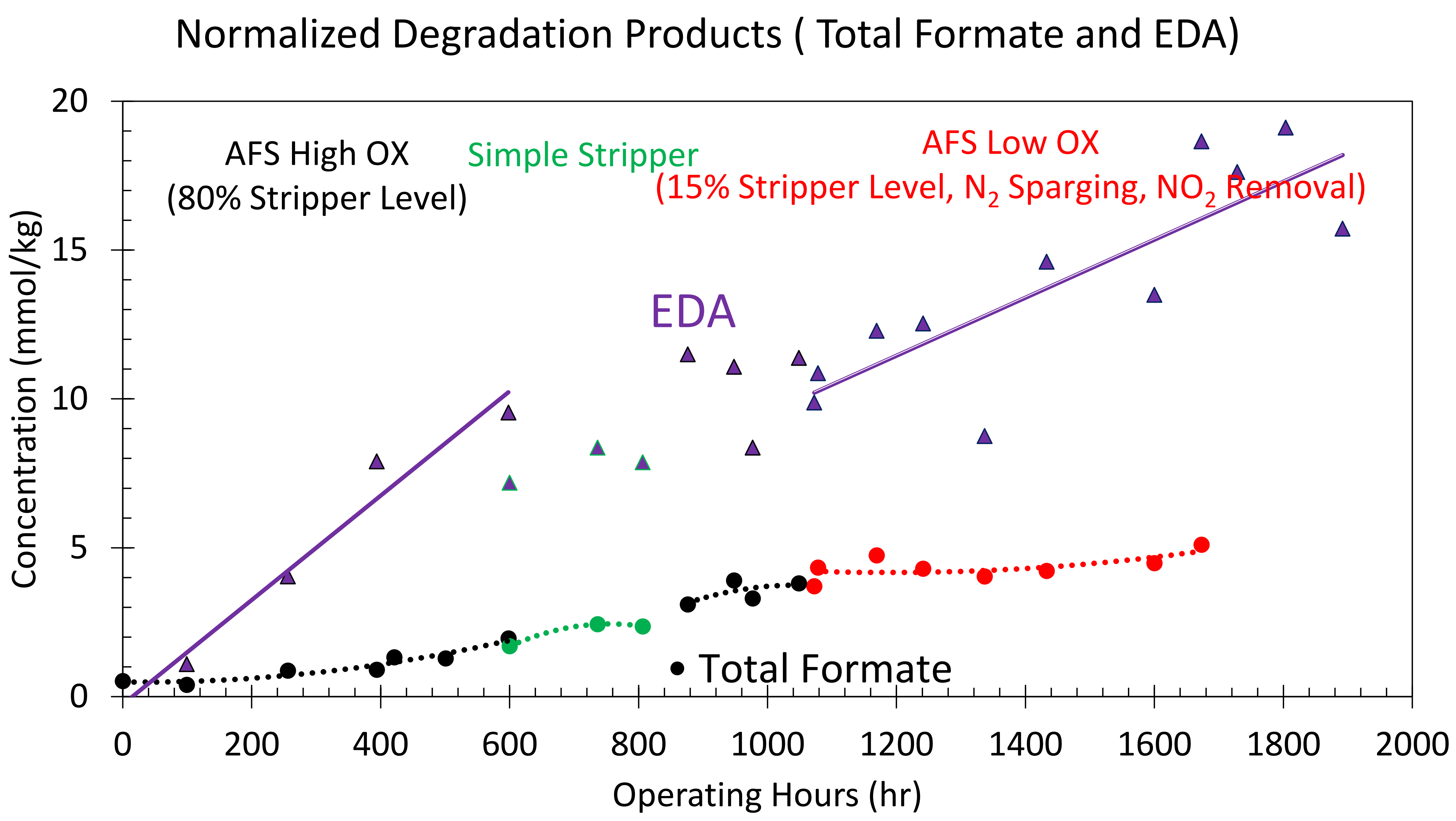

PZ Oxidation estimated from NH3 = 0.17 lb PZ/t CO2
Assume 1 mol NH3/mol PZ Oxidized
AFS High Ox
(80%
Stripper Level)
Simple Stripper
AFS Low Ox
(15% Stripper Level, N2 Sparging, NO2 Removal)
NH3 at Absorber out (ppm)
Operating Hours (hr)
7
6.5
6
5.5
5
4.5
4
3.5
3
600
800
1000
1200
1400
1600
1800



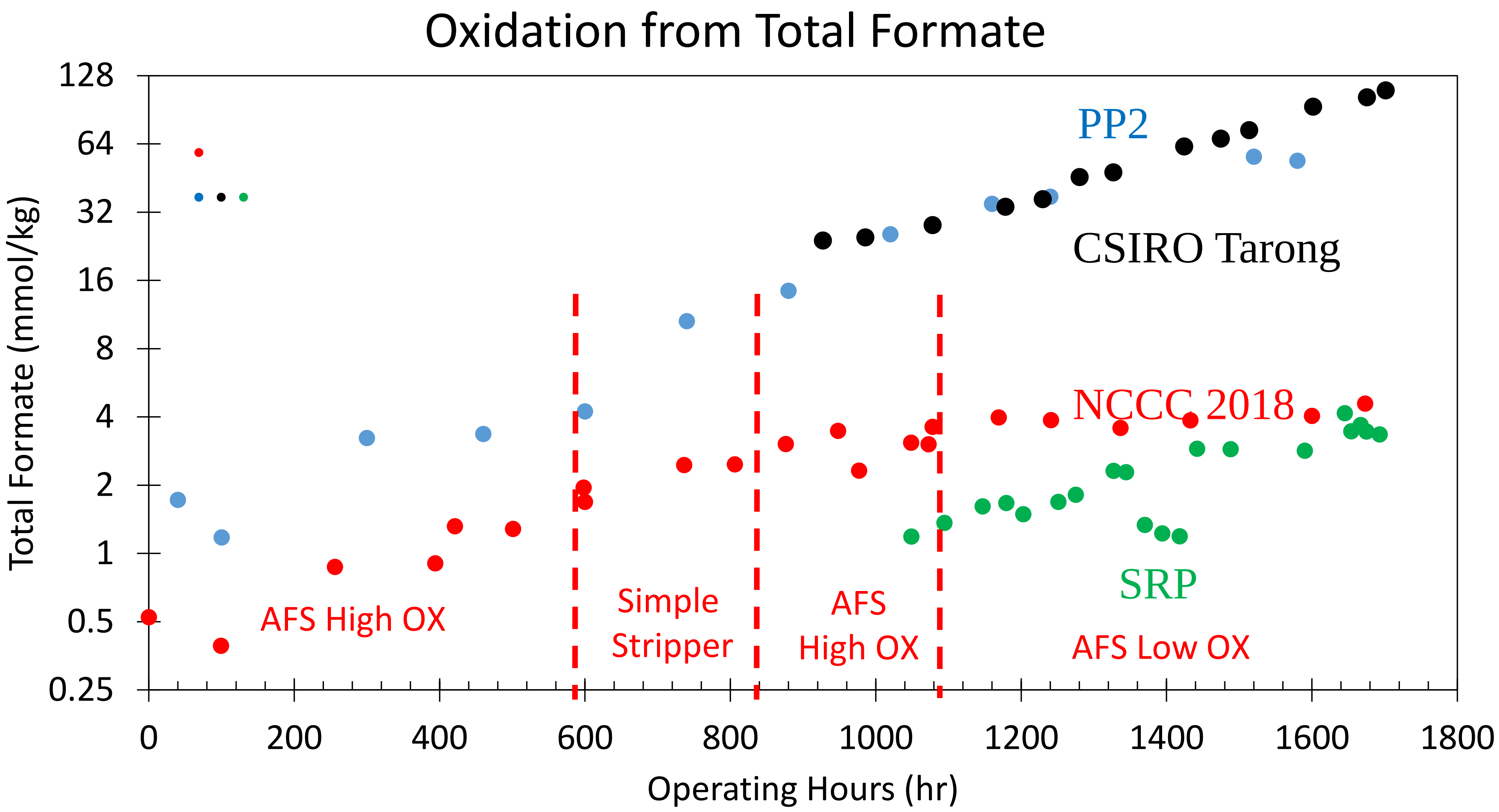
PZ oxidation as suggested by dissolved Fe
Dissolved Fe (mmol/kg)
0.64
0.32
0.16
0.08
0.04
0.02
0.01
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Operating Hours (hr)
AFS High OX
Simple Stripper
AFS High OX
AFS Low OX
NCCC 2018



Comparison of Dissolved Fe to other PZ pilot data
PP2
CSIRO Tarong
AFS High OX
AFS
High OX
AFS Low OX
Simple
Stripper
NCCC 2018
SRP
0.64
0.32
0.16
0.08
0.04
0.02
0.01
Fe^{2+} (mmol/kg)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Operating Hours (hr)



Normalized Degradation Products (Total Formate and EDA)
AFS High OX
(80% Stripper Level)
Simple Stripper
AFS Low OX
(15% Stripper Level, N_2 Sparging, NO_2 Removal)
EDA
Total Formate
Concentration (mmol/kg)
Operating Hours (hr)
0
5
10
15
20
0
200
400
600
800
1000
1200
1400
1600
1800
2000


Oxidation from Total Formate
Total Formate (mmol/kg)
128
64
32
16
8
4
2
1
0.5
0.25
0
200
400
600
800
1000
1200
1400
1600
1800
Operating Hours (hr)
PP2
CSIRO Tarong
NCCC 2018
SRP
AFS High OX
Simple
Stripper
AFS
High OX
AFS Low OX

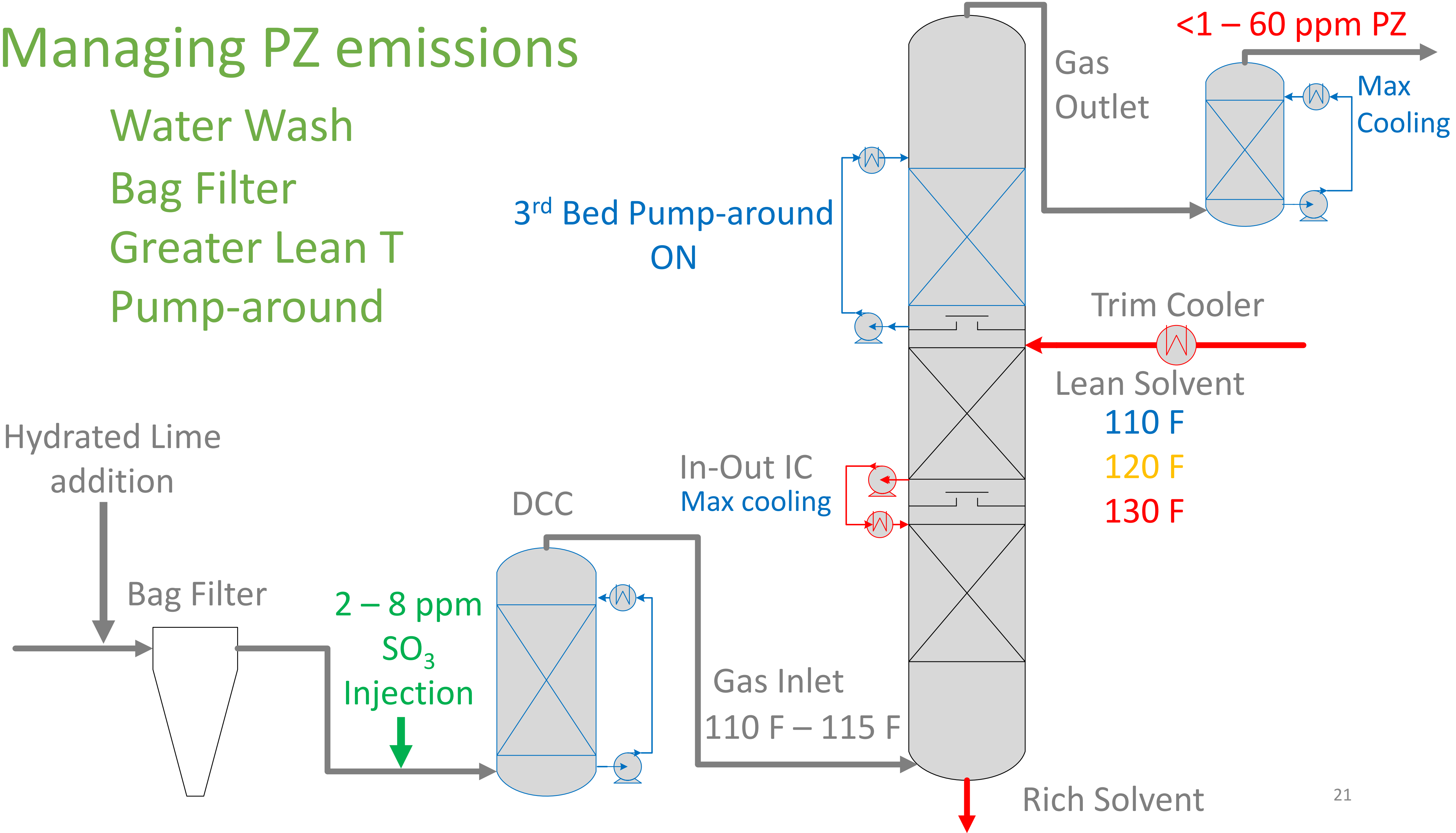
0.5 – 5 ppm PZ emissions at 0 – 4 ppm SO_3

Aerosol managed by high Lean T

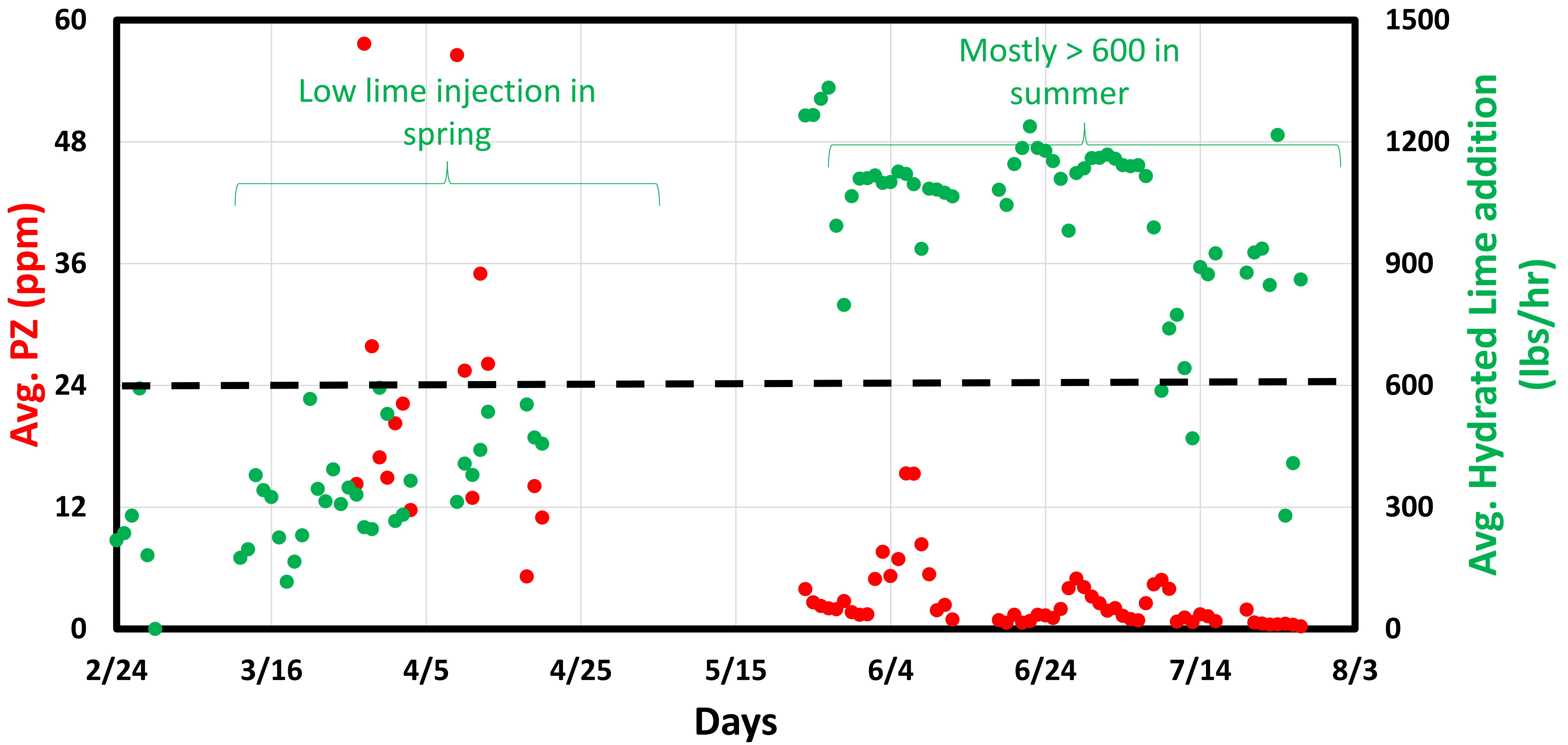
and additional pump-around water wash

Managing PZ emissions

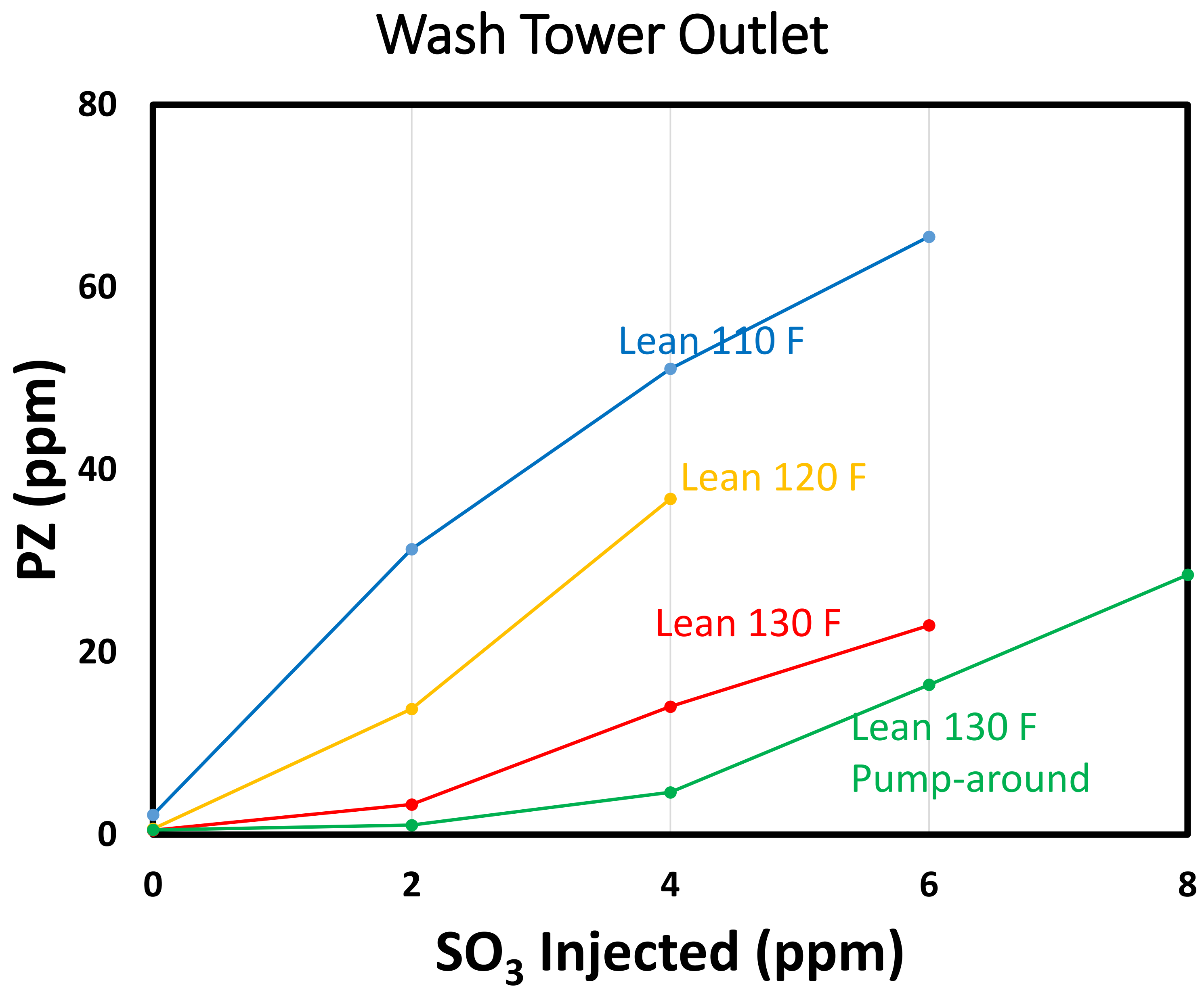
- Water Wash
- Bag Filter
- Greater Lean T
- Pump-around



Low $Ca(OH)_2$ correlates with high PZ

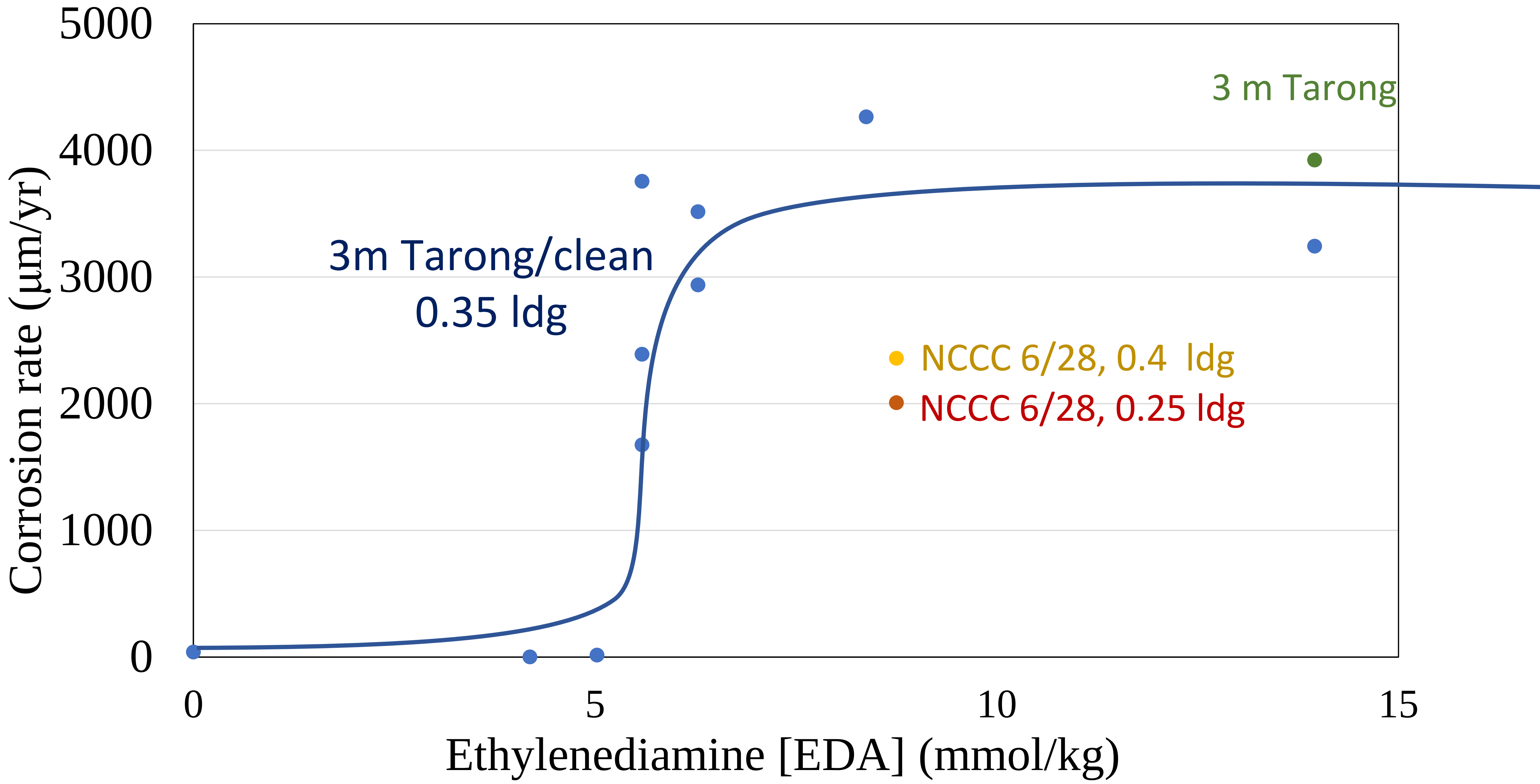


Higher lean T & 3rd Bed Pump-around suppress PZ



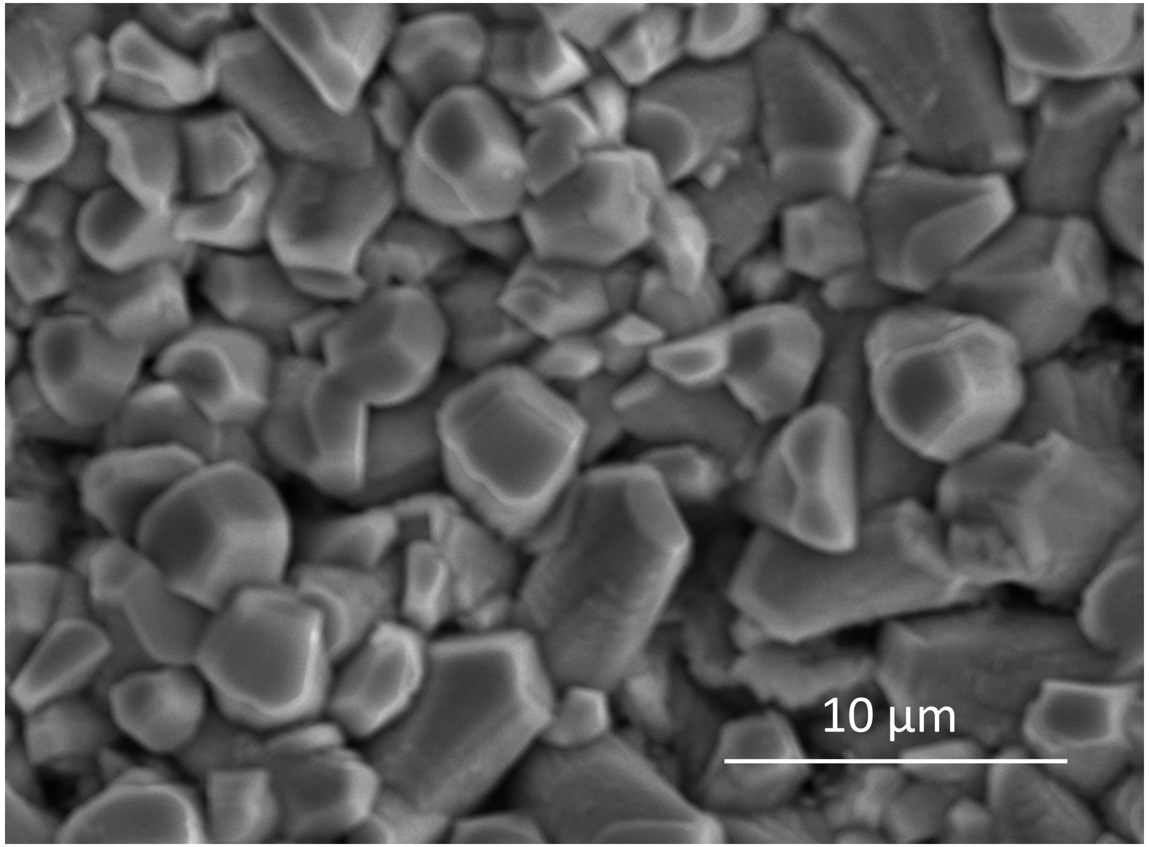
Carbon Steel frequently protected by $FeCO_3$
Stainless mostly untouched
Degradation products increase corrosion

Corrosion occurs at a critical concentration of degradation products
Bench-scale measurement by ER probe at reducing conditions, 120^{o}C

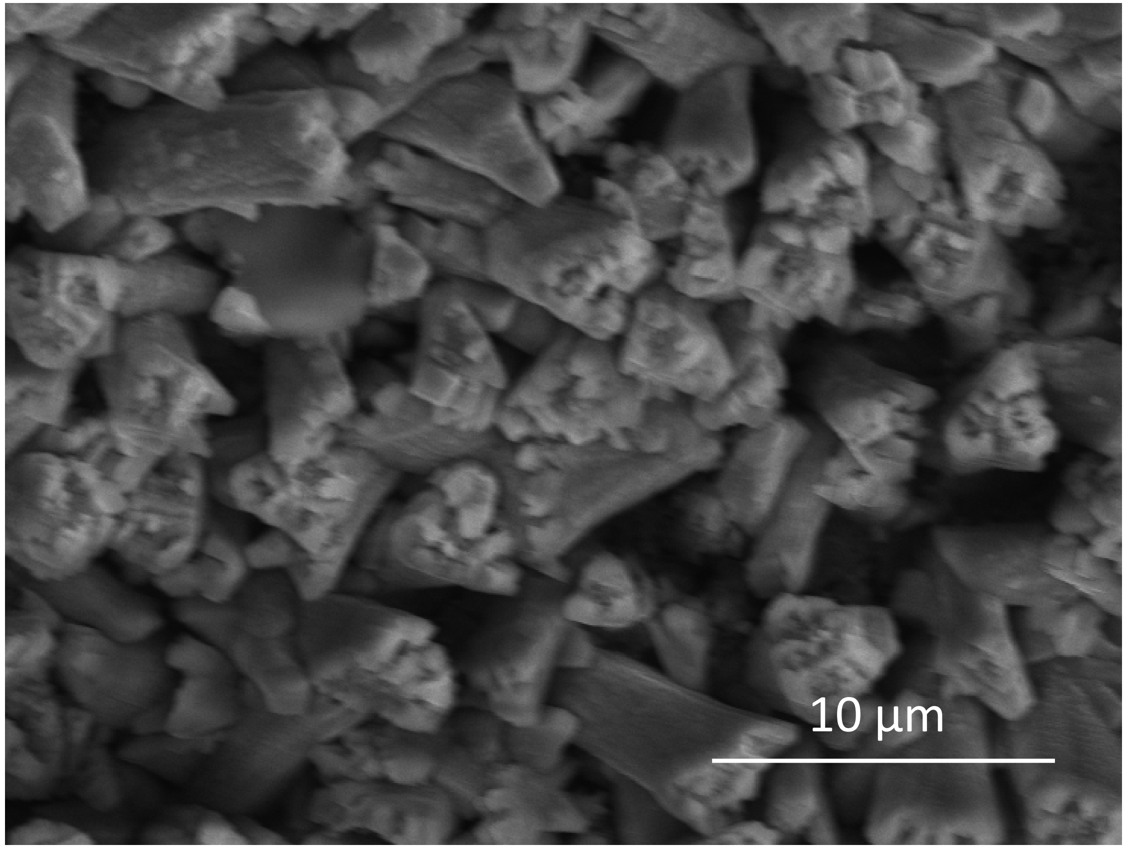


Not all $FeCO_3$ films are protective.

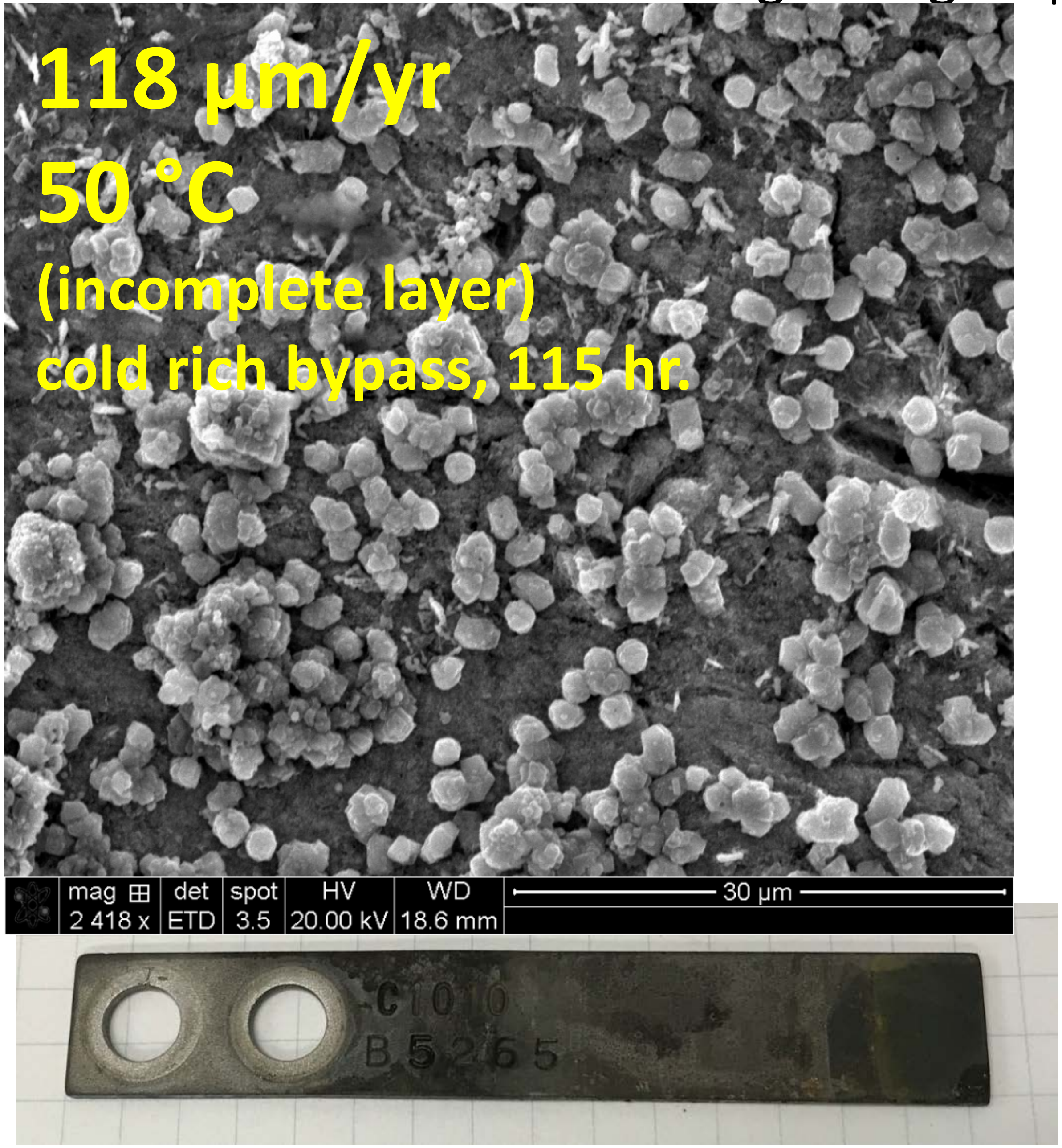
Not corroded
36 wt% Tarong PZ

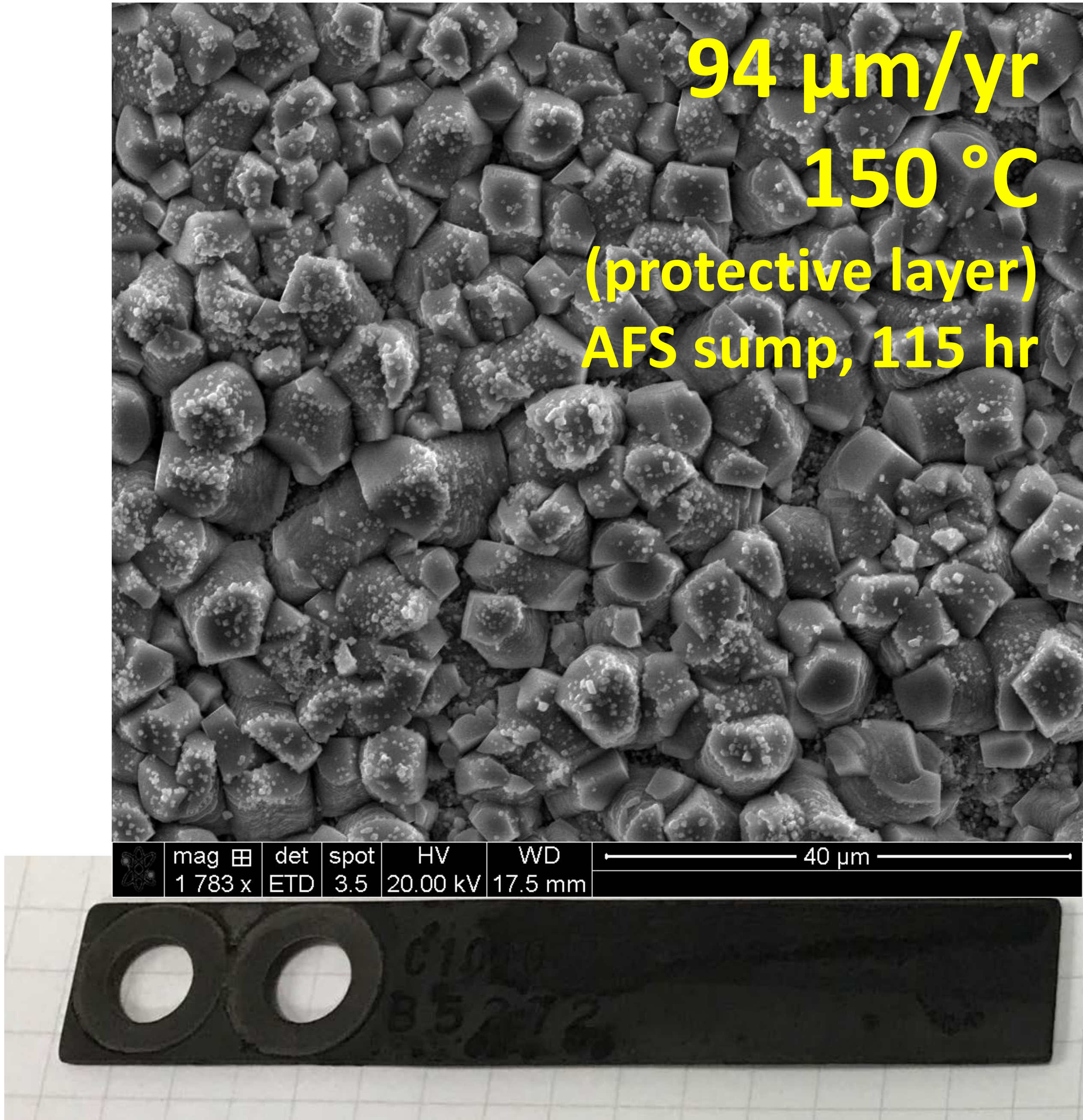


Corroded
60 wt% Tarong PZ



Protective $FeCO_3/Fe_3O_4$ forms on C1010 at high T



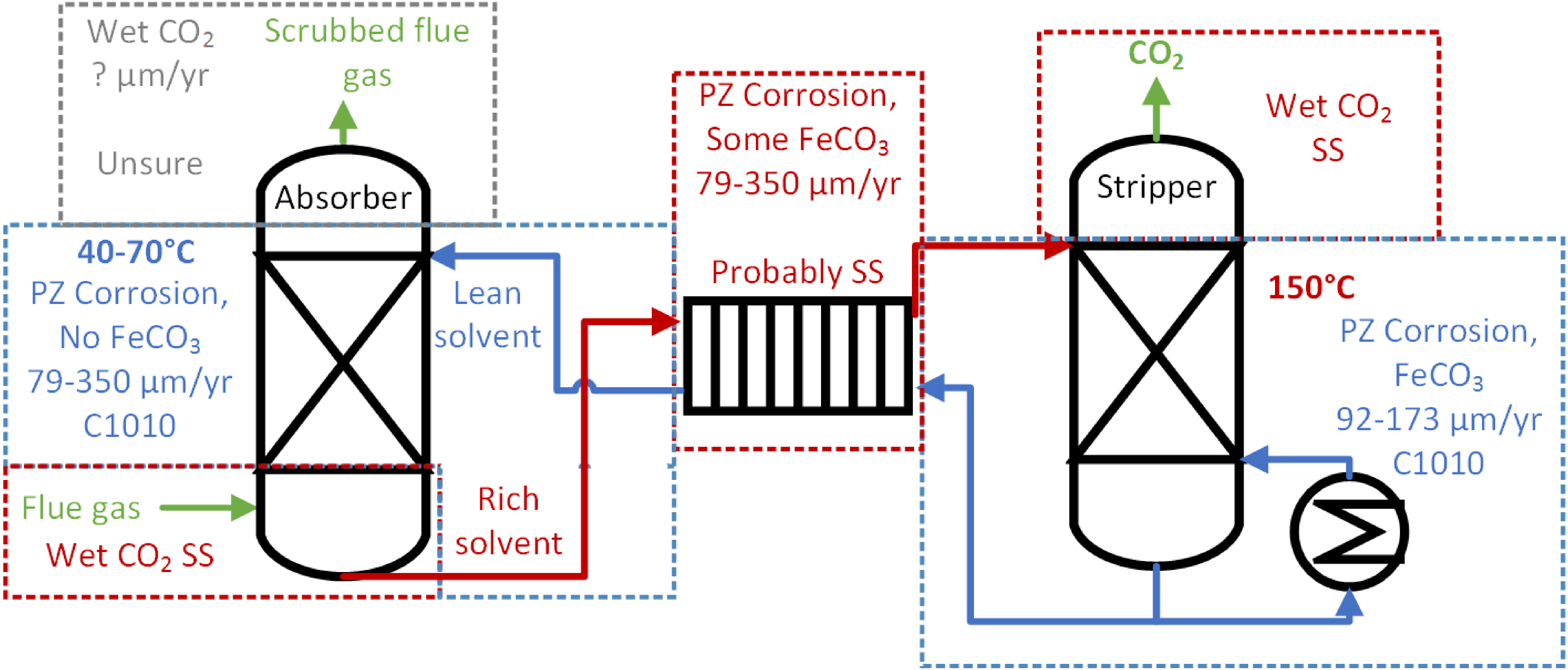


NCCC C1010 Coupon Corrosion, 114 hrs of contact

Location	Corrosion (µm/yr)	Comment
Absorber sump	79	Slow oxidation
Absorber middle	105	Slow oxidation
Cold, lean	350	High velocity?
Cold rich bypass	118	Slow oxidation
Warm rich bypass	92	protected
Hot rich	173	Flashing
AFS sump	94	Protected

- **Stainless analysis in progress, but no signs of high corrosion**

PZ Equipment Recommendations



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Acknowledgements

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- Operations by Southern Co.: Tony Wu, Laura Uhrig, Graham Bingham

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