FLUOR
Safer Together

BASF
We create chemistry

ExxonMobil
Energy lives here™

2020 Brimstone Virtual Vail Sulfur Symposium

Sulphur Recovery with COPE® Oxygen Enrichment Claus and OASE® sulfexx™ Tail Gas Treating

Jenny Seagraves, ExxonMobil Research and Engineering
Thomas Chow, Fluor Energy & Chemicals
Blake Morell, BASF Corporation

Agenda

- Key Drivers Affecting Sulphur Recovery
- Impacts and Potential Options
- Overview of COPE® Oxygen Enrichment (OE) Claus and OASE® sulfexx™ in Tail Gas Treating
- Case Study – Oxygen Enrichment vs. Air Only Operation
- Oxygen Enhanced Claus Carbon Dioxide Recovery Process (OEC²RP)
- Key Takeaways

Future landscape at a glance

Key drivers affecting sulphur removal:

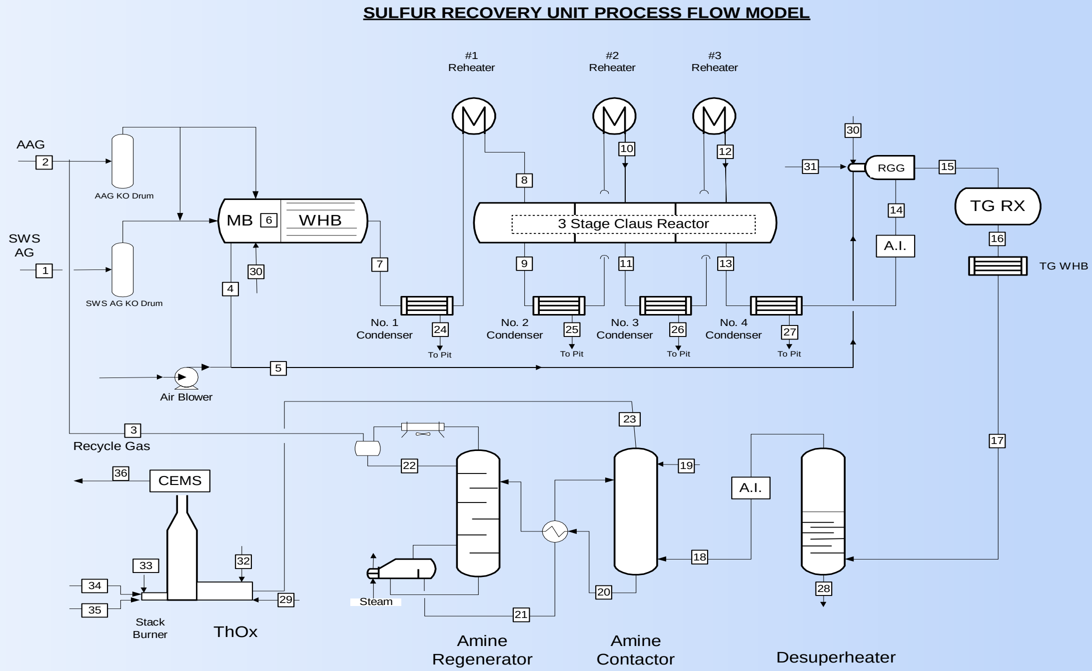
- Increase demand for energy
  - By 2040, global energy needs rise by 20% [1]
  - Electricity demands nearly double in non-OECD countries[1]
  - Natural gas expands role to meet a variety of needs
- Cleaner fuels, lower emissions and decarbonization
  - Higher sulphur content in feedstocks
  - IMO 2020 (Global sulphur cap of 0.5% for marine fuel)
  - Reduce SO_2 emissions
  - Energy conservation and reducing overall CO_2 footprint
- Highly integrated facilities
  - Crude to chemicals requires even more stringent purification
  - Shift in product demand patterns requires flexibility

[1] Source: 2019 Outlook for Energy, A View to 2040. Exxon Mobil Corporation

Potential Options

Adding new SRU/TGTU trains is expensive. Alternative is to modify equipment for more capacity or for more flexibility

- Increase SRU capacity with OE Claus technology such as COPE®
- As a result, increase in sulphur load requires additional TGTU capacity.
- OASE® sulfexx™ is high capacity solvent for sulphur removal.
- Replace MDEA with OASE® sulfexx™ to avoid building additional TGTU trains.
- OEC²RP can provide a cost effective option for recovering CO_2 for Enhanced Oil Recovery (EOR)



Oxygen Enrichment – Capacity Increase

$$H_2S + ½ O_2 + x N_2 \rightarrow H_2O + S + x N_2$$

(condensed)

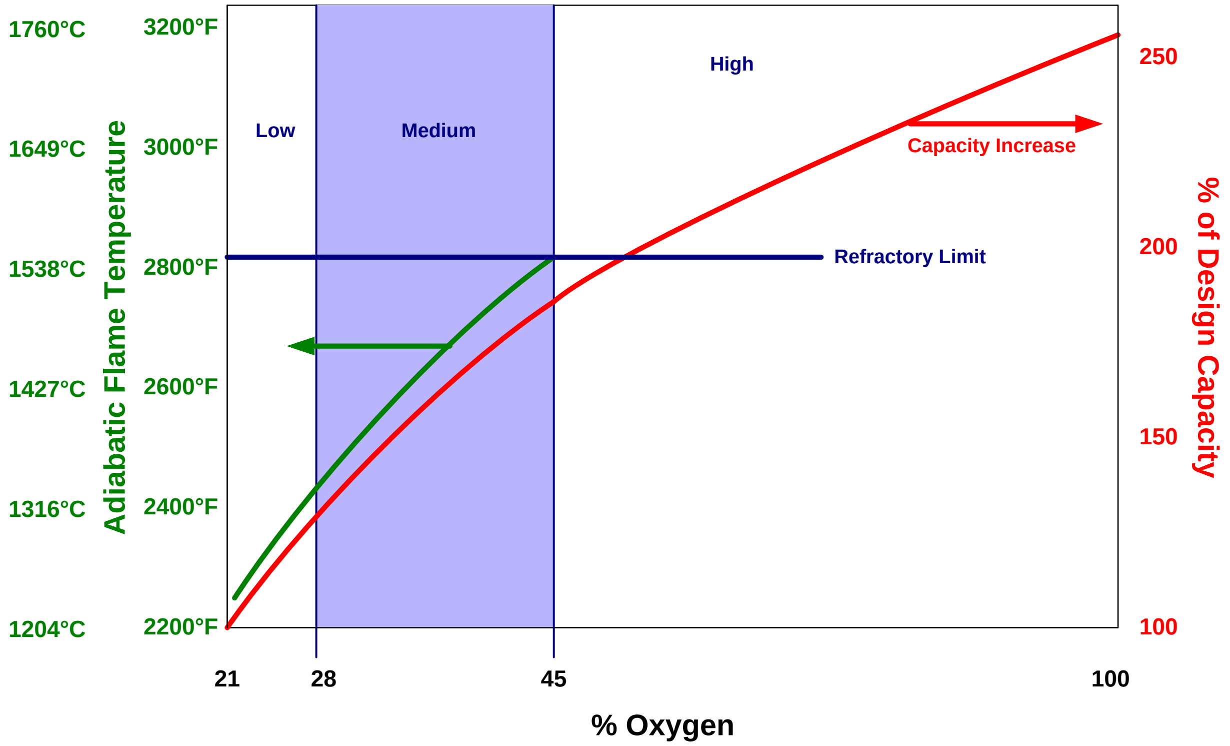
Oxygen Enrichment Level	% O_2	x	Tail Gas Flow Rate ($H_2O + N_2$)	Capacity Increase
0% (Air Only)	21	1.9	1 + 1.9 = 2.9	Base
Low Level – 22% to 28%	28	1.3	1 + 1.3 = 2.3	26%
Medium Level – 29% to 45%	45	0.6	1 + 0.6 = 1.6	81%
High Level – 46% to 100%	99.5	~0	1 + 0.0 = 1.0	190%

Notes:

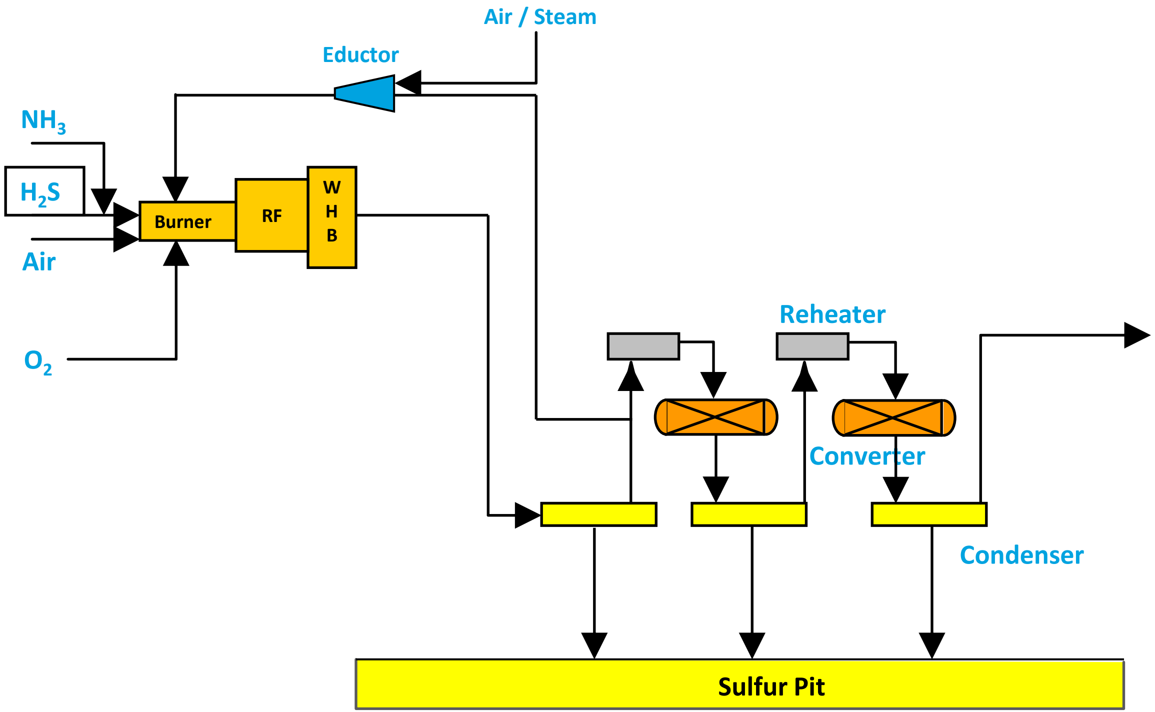
1. Other components in air such as argon and carbon dioxide are included in coefficient x.

2. For simplification purposes, water vapor in air has not been included in the summary as it would only have a minor effect on the calculation.

Three Levels of Oxygen Enrichment



Principle of Fluor/GAA Patented COPE® Process

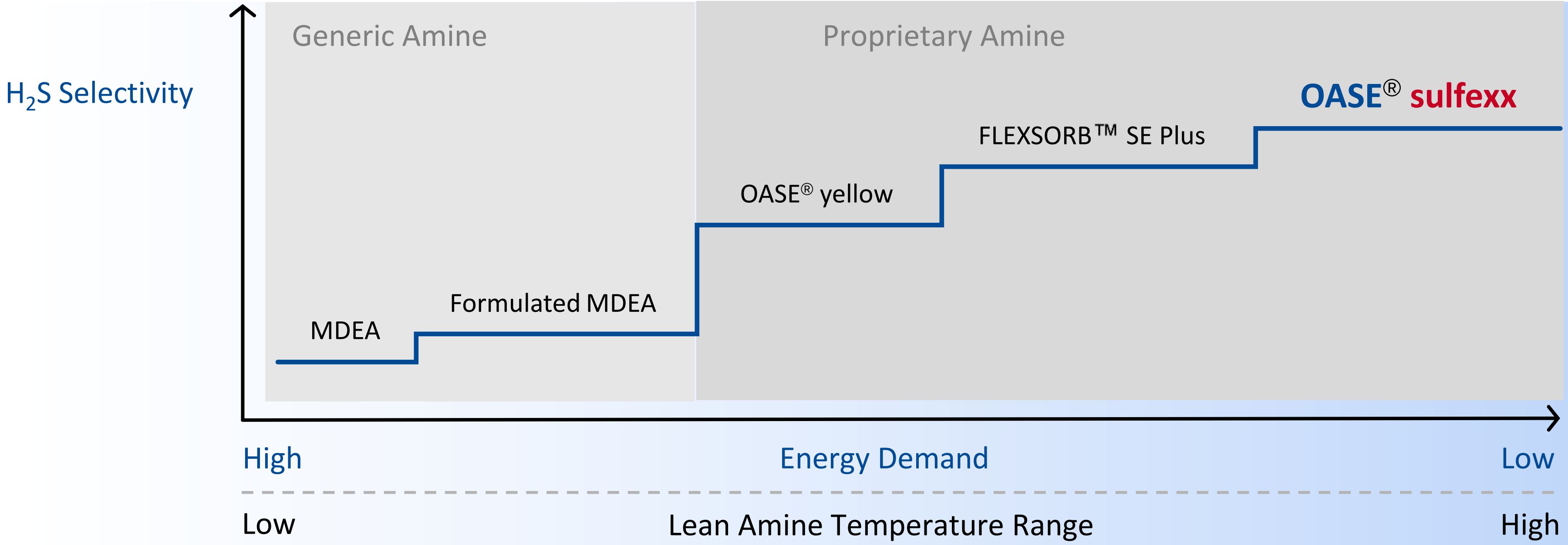


ExxonMobil BASF We create chemistry FLUOR

COPE® and COPE II® Oxygen Enrichment Claus Technology

- **Commercially Proven Technology**
  - Over 80 units worldwide
  - Used in various sizes of SRU/TGTUs and are being considered for world scale sulphur plants
- **Enhance Sulphur Plant Processing Capacity**
  - Expand existing sulphur plant processing capacity, up to 150% of original design capacity
  - Smaller equipment for new sulphur plant
- **Low Life Cycle Costs (Low CAPEX & OPEX)**
  - Implementation requires much lower CAPEX than building new plants (about 30%)
  - Lower operating and maintenance costs
  - Higher operating reliability and flexibility
  - No additional plot space for implementing into existing SRU/TGTU
  - Smaller plot space for new SRU/TGTU

Selective H_2S Tail Gas Treating Solutions



OASE® sulfexx™

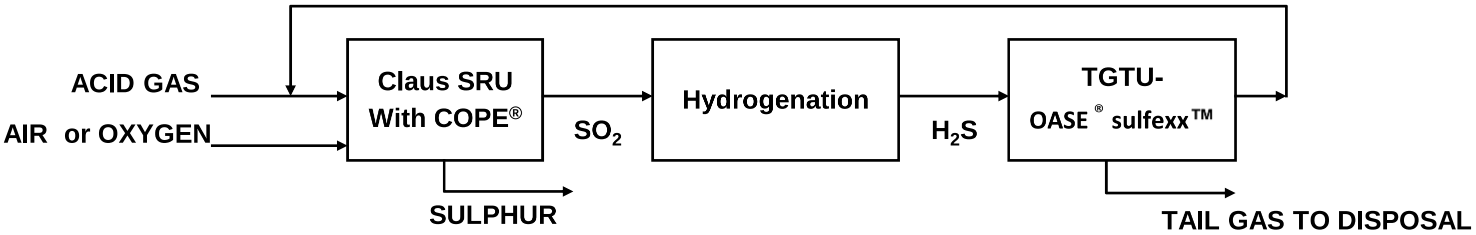
- Meets Environmental Regulations
  - High sulphur recovery / Minimize SO_2 emission
  - Able to achieve <5 ppmv H_2S
- Low Life Cycle Costs (Low CAPEX & OPEX)
  - High absorption capacity
  - High selectivity for H_2S over CO_2 (typically CO_2 slip $\geq$ 90%)
  - Smaller equipment for new units
  - Utilize existing equipment for expansion (debottleneck)
  - Lower circulation rate resulting in lower steam and electricity consumption
  - Stable solvent resulting in lower makeup and little to no reclaiming required

Case Study – Formulated MDEA vs. OASE® sulfexx™

	Formulated MDEA	OASE® sulfexx™
Solvent Circulation Rate, m^3/h	Base	Base-50%
Absorber Feed Gas and Lean Solvent Temperature, °C	38	60
Gas and Lean Solvent Cooling	Air Cooling + Large Water Cooling or Propane Refrigeration	Air Cooling
Plot Space	Large	Medium
Robustness of Operation	High	Very high
Capital Cost Savings	Base	Base-10%
Operating Cost Savings	Base	Base-55%

Case Study – Feed Gas Basis

Dry Composition	SRU Feed Gas	OASE® sulfexx™ Absorber Inlet Gas		
		1000 MTPD Air Only	1500 MTPD 32% OE	1500 MTPD 100% OE
CO_2, mol%	28	18	28	71
H_2S, mol%	71	3	5	9
N_2, mol%	0	76	61	0
H_2, mol%	0	2	5	19
Other, mol%	1	1	1	1
Total, mol%	100	100	100	100



Case Study – Circulation Comparison with Air and Oxygen Enrichment

	SRU Feed Gas Sulphur, MTPD	Absorber Inlet Gas, kgmol/h	Solvent Circulation Rate, m^3/h	Reboiler Duty , MW	Circulation / Feed Gas Sulphur, m^3/MT
Air Only (Formulated MDEA)	1000	X	Y	Q	11.80
Air Only (FLEXSORB™ SE Plus)	1000	X	53% of Y	57% of Q	6.27
Air Only (OASE® sulfexx™)	1000	X	51% of Y	52% of Q	5.96
32% O_2 Enrichment (OASE® sulfexx™)	1500	85% of X	63% of Y	69% of Q	4.96
100% O_2 Enrichment (OASE® sulfexx™)	1500	37% of X	58% of Y	78% of Q	4.57

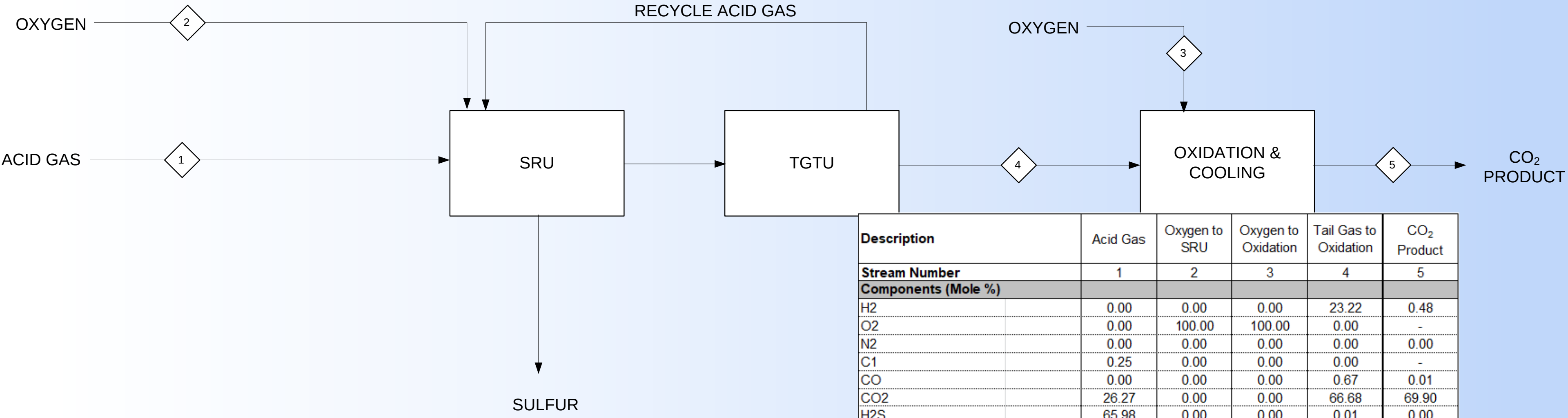
Absorber overhead < 50 ppmv H_2S

100% Oxygen Enrichment – Further Opportunities

- SRU operating on air only will have a significant amount of nitrogen in the treated tail gas from the TGTU
- SRU operating with 100% oxygen enrichment will have no or very low concentration of nitrogen in the treated tail gas from the TGTU
- Treated tail gas will contain mostly CO_2, H_2 and H_2O with no or small amounts of N_2
- Treated tail gas from a 100% Oxygen Enriched SRU is a good candidate for alternative methods of CO_2 recovery
- Fluor's OEC^2RP is cost effective for CO_2 recovery if implemented with 100% COPE® Oxygen Enriched SRU and OASE® sulfexx™ TGTU

OEC^2RP is Fluor's patent pending Oxygen Enhanced Claus Carbon Dioxide Recovery Process

OEC²RP Block Flow Diagram



Description		Acid Gas	Oxygen to SRU	Oxygen to Oxidation	Tail Gas to Oxidation	CO_2 Product
Stream Number		1	2	3	4	5
Components (Mole %)						
H2		0.00	0.00	0.00	23.22	0.48
O2		0.00	100.00	100.00	0.00	-
N2		0.00	0.00	0.00	0.00	0.00
C1		0.25	0.00	0.00	0.00	-
CO		0.00	0.00	0.00	0.67	0.01
CO2		26.27	0.00	0.00	66.68	69.90
H2S		65.98	0.00	0.00	0.01	0.00
COS		0.00	0.00	0.00	0.08	0.00
SO2		0.00	0.00	0.00	0.00	0.01
H2O		7.31	0.00	0.00	9.35	29.60
Molar Flow	lbmol/hr	19,692.5	5,865.1	946.0	7,989.7	7,705.5
Mass Flow	lb/hr	699,594.0	187,682.4	30,272.6	253,552.7	278,261.1
Standard Gas Flow	MMSCFD	179.4	53.7	8.7	73.0	70.5
Actual Liquid Flow	USGPM	—	—	—	—	—
Stream Data						
Temperature	°F	129	118	50	122	156
Pressure	psig	12.9	12.0	25.3	4.4	0.0
Molecular Weight		35.53	32.00	32.00	31.73	36.11

OEC^2RP For Recovering CO_2 from Gas Plant SRU/TGTUs

Benefits of OEC^2RP

- Much lower capital and operating costs relative to investment and energy intensive CO_2 recovery processes available to date
- Production of high pressure steam
- Produces a high purity CO_2 product
- Simple design with all process steps commercially proven
- Small footprint

ExxonMobil | BASF We create chemistry | FLUOR

Key Takeaways

- COPE® and COPE II® oxygen enrichment enables higher sulphur processing capacity
- A high capacity solvent such as OASE® sulfexx™ is complementary and effective in handling increased sulphur load gained from OE
- FLEXSORB™ SE/ SE Plus have more capacity for H_2S than Formulated MDEA (methyldiethanolamine) to avoid additional capital investments
- OASE® sulfexx™ has even higher capacity for H_2S than FLEXSORB™ SE and SE Plus and will further reduce the unit CAPEX/OPEX investments.
- Combined technologies allow facility the flexibility to operate from full air to 100% oxygen at anytime according to processing needs
- Further opportunities to recovery CO_2 for Enhanced Oil Recovery (EOR) by using Fluor’s patent-pending OEC^2RP

Thank you

Questions?

Backups

Definitions

- COPE® - Claus Oxygen Process Enhancement
  - Includes oxygen enrichment level from 22% up to 100%

- COPE II® - Claus Oxygen Process Enhancement second Generation
  - Process applies to high level oxygen enrichment (> 40%) to SRUs processing refinery amine acid gas and Sour Water Stripper off-gases that requires temperature moderation in the Claus Reaction Furnace

- OE Claus - Oxygen Enrichment Claus technology in general

- OEC^2RP -- Fluor's patent-pending Oxygen Enhanced Claus Carbon Dioxide Recovery Process
  - A CO_2 recovery process typically from mega size SRU/TGTUs in gas plants featured with high level oxygen enrichment Claus and high performance TGTU such as those using FLEXSORB™ SE Plus or OASE® sulfexx™ technology.

Definitions

- FLEXSORB™ SE and FLEXSORB™ SE Plus Technology
  - Solvent technology based on ExxonMobil's proprietary sterically hindered amine for selective H_2S removal. Applications include acid gas enrichment, tail gas treating, and sour gas treating.

- SRU – Sulphur Removal Unit

- TGTU – Tail Gas Treating Unit

- MDEA – methyldiethanolamine
  - Common solvent used for sour gas treating. MDEA have other industrial uses including urethane catalyst, textile softeners, pH control, and epoxy resin curing agents.