CARBON CAPTURE SOLUTIONS
HONEYWELL UOP

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HONEYWELL UOP – SUSTAINABLE TECHNOLOGY SOLUTIONS

29th Oct 2024

Honeywell
UOP

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AGENDA

I. Honeywell UOP Overview

II. Carbon Capture Technology Pathways

III. Advanced Solvent Carbon Capture (ASCC)

IV. Cryogenic Carbon Capture + PSA

V. Low Carbon H_2 ATR Solutions

VI. Low Carbon H_2 SMR Retrofit Solutions

VII. Blue Hydrogen Case Studies

VIII. Conclusions

IX. Questions

HONEYWELL
UOP AT A GLANCE

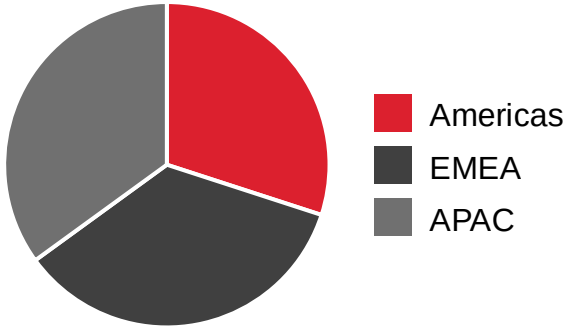
100+ Years of Global Expertise and Leading Technology Development

UOP TECHNOLOGY POWERS

- **90%** of biodegradable detergents
- **70%** of the world's polyester
- **60%** of the world's gasoline
- **60%** of the world's on-purpose propylene
- **60%** of the world's paraxylene
- **50%** of the world's renewable fuels
- **40%** of LNG processed
- **40MT** tons of captured CO_2 (as of June 2024)

GLOBAL REACH

Diversified regional presence that can effectively react to changes in demand



NEW TECHNOLOGIES

Honeywell UOP creates new technologies that convert oil and natural gas into transportation fuels, energy, and petrochemicals

EXPERTISE

Broadest range of downstream refining and petrochemical technologies; leading process technology licensor

2,000
Engineers and scientists

4,900
Active patents and applications

LARGEST
process licensing organization
in the world

31 out of **36**
refining technologies in use today were developed by
UOP

SUSTAINABLE TECHNOLOGY SOLUTIONS

A New Business Unit for Honeywell

RENEWABLES FUEL

Reducing Diesel and Jet GHG Emissions >80%[1]

UOP Ecofining™, Ethanol to Jet, and UOP eFining™ can deliver **substantial profits** plus **significant reduction in GHG emissions**

CARBON CAPTURE/ BLUE HYDROGEN

Low Emissions Fuel for Hard to Decarbonize Applications

Honeywell UOP provides **efficient, tailored CO_2 capture** for pre-, post-, and oxy-combustion applications

GREEN HYDROGEN

Driving toward Zero Emissions Power

UOP proprietary catalyst coated membrane can reduce PEM electrolyzer stack capex by 35%[2]

PLASTICS CIRCULARITY

Removing Oil & Gas Extraction from Plastic Production

Honeywell Upcyle Plastics Recycling can **increase waste plastic circularity** if collection and sorting is improved

ENERGY STORAGE

Reducing CO_2 Emission

Ready-now technology to significantly **reduce CO_2 emissions** from energy and industrial point sources

Committed to Commercialization of Sustainable Technologies

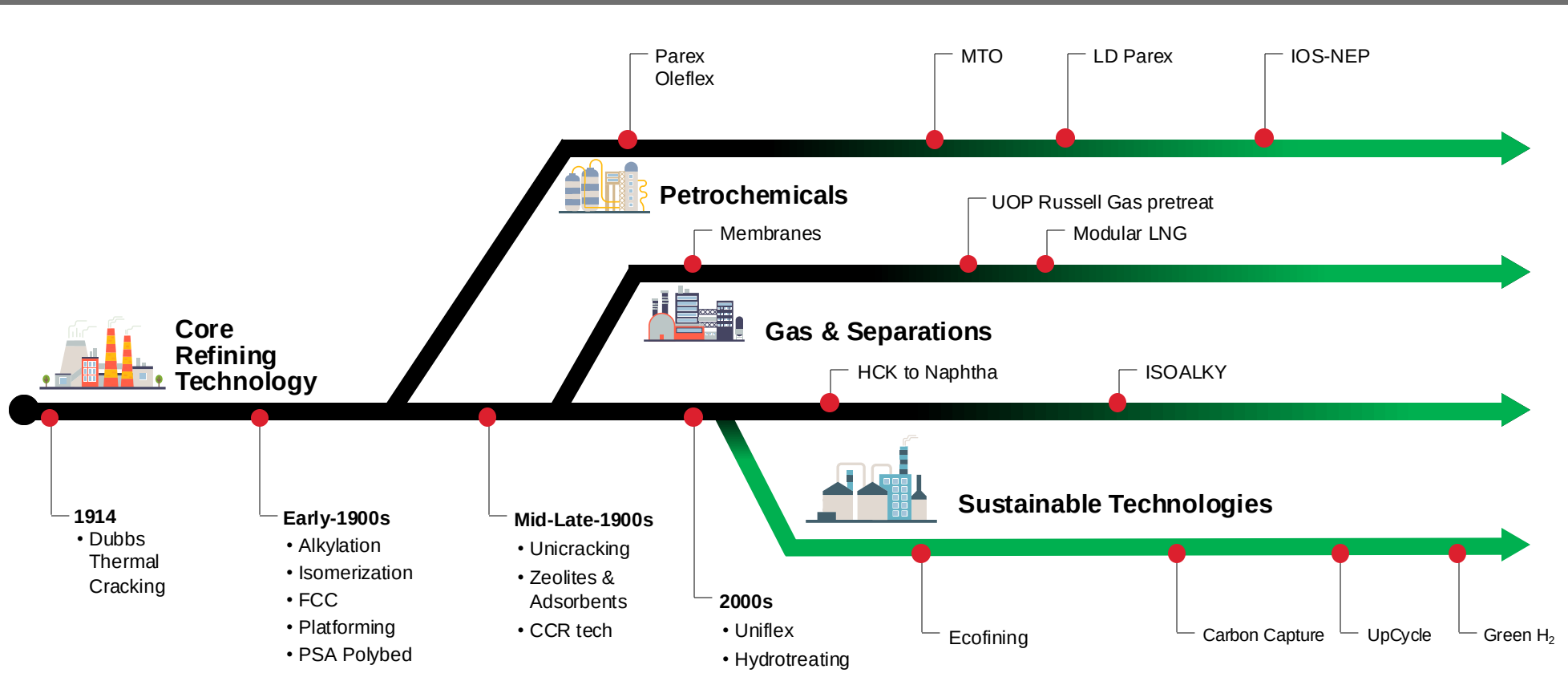
1 Greenhouse gas emission savings calculations based on California Air Resources Board methodologies

2. based on a PEM water electrolysis system using renewable power to produce 2,220 MT H2/y with 8,760 operating hours/year using UOP internal lab test results of UOP's HiFlux-114P PEM CCM and a commercially available PEM CCM

BUILDING ON A STRONG CORE FOUNDATION

UOP Core Foundations | Enabling the Future of Sustainable Energy Technologies

UOP technology enhanced by services and digital offerings

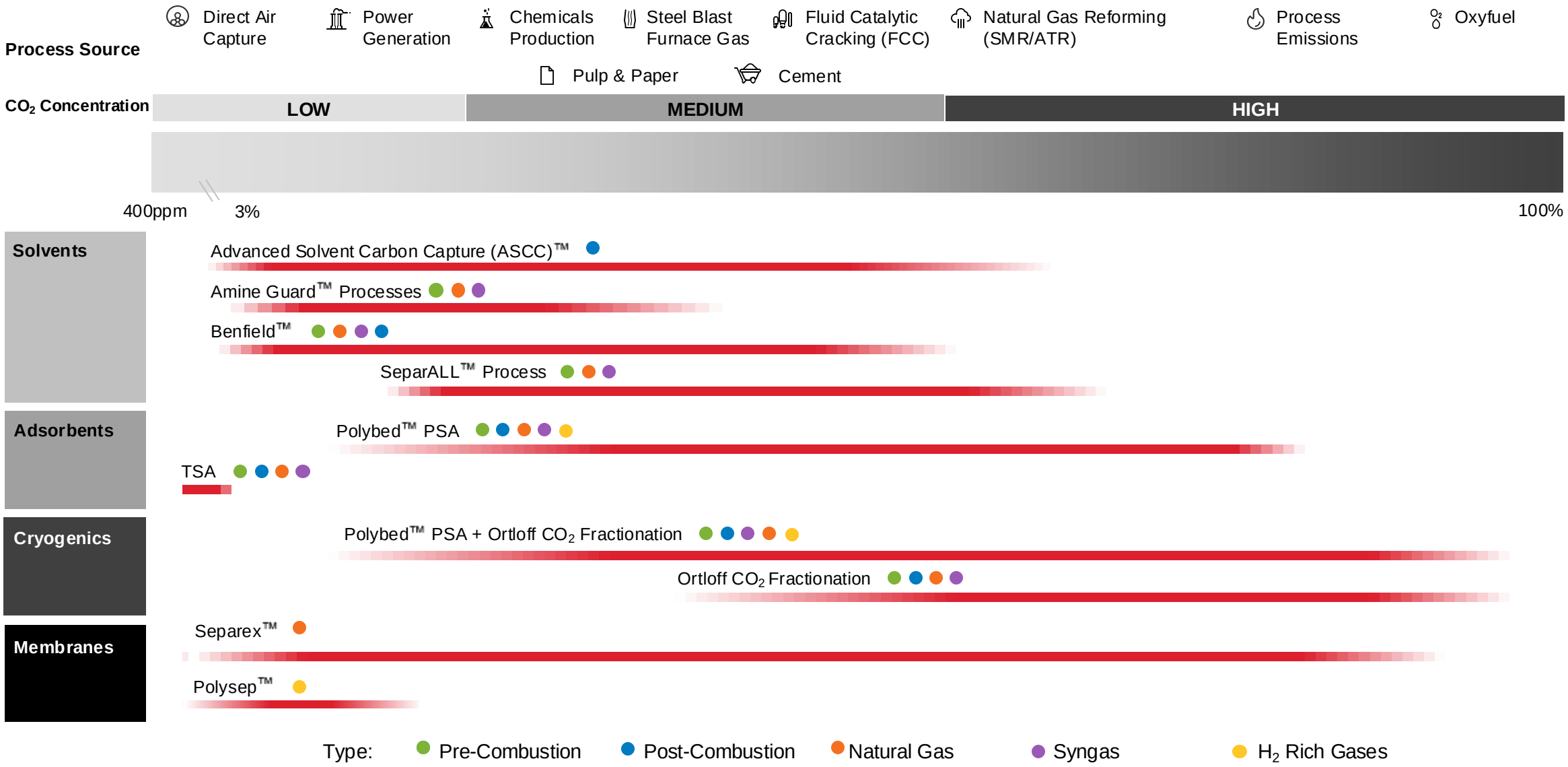


Enabling the Energy Transition with end-to-end energy technology portfolio

Sources: UOP database

CARBON CAPTURE TECHNOLOGY PATHWAYS

HONEYWELL CO_2 SOLUTIONS



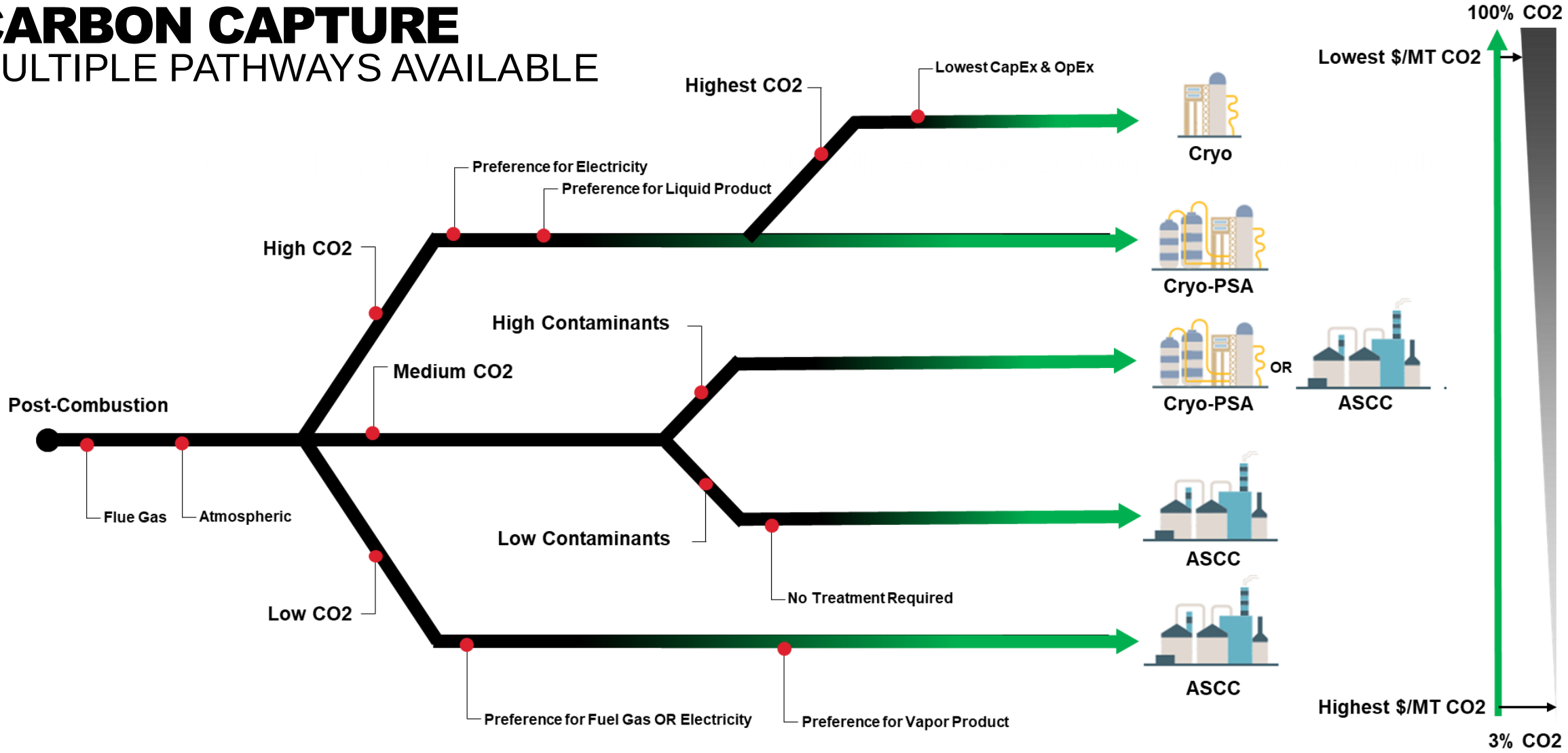
CARBON CAPTURE REFERENCES

Existing Units Capture Ready & Capturing			
#	Facility	Technology	Installed CO_2 Capture Capacity (kMTA)
1	FPSO	Membranes	26,000
2	Gas Processing Plant	Cryo-Selexol	8,400
3	Fertilizer Plant	Selexol	1,000
4	Power Plant Indiana	Selexol	1,500
5	Gas processing plants	AGFS, Selexol, Benfield	>6Bscfd of installed capacity transitioning to CO_2 Capture plants
6	Bulk CO_2 Removal Plants	Separex	>3Bscfd of Bulk CO_2 removal capturing & capture ready
Recent Awards			
1	ExxonMobil Baytown	Cryo-PSA	7,000
2	Wabash Valley Resources	Cryo-PSA	1,650
3	Duke DOE OECD Selection	ASCC	3,600
4	Ecopetrol, FCC	ASCC	75
5	SMR Flue Gas	ASCC	250
6	CCGT Demo	ASCC	10
7	Confidential	Cryo-PSA	6,700
8	Calpine Pastoria	ASCC	Confidential
9	Confidential	ASCC	100

Capturing >15 Mt per year with capacity to capture more

Sources: ExxonMobil to Deploy Honeywell Carbon Capture Technology, Honeywell Technology Enables Large U.S. Carbon Capture And Storage Project, OCED_CCEEEDs_AwardeeFactSheet_Duke_1.5.2024.pdf (energy.gov), Ecopetrol selects Honeywell technology for advanced solvent carbon capture study (digitalrefining.com), https://www.energy.gov/fecm/project-selections-foa-2614-carbon-management-round-3

CARBON CAPTURE
MULTIPLE PATHWAYS AVAILABLE

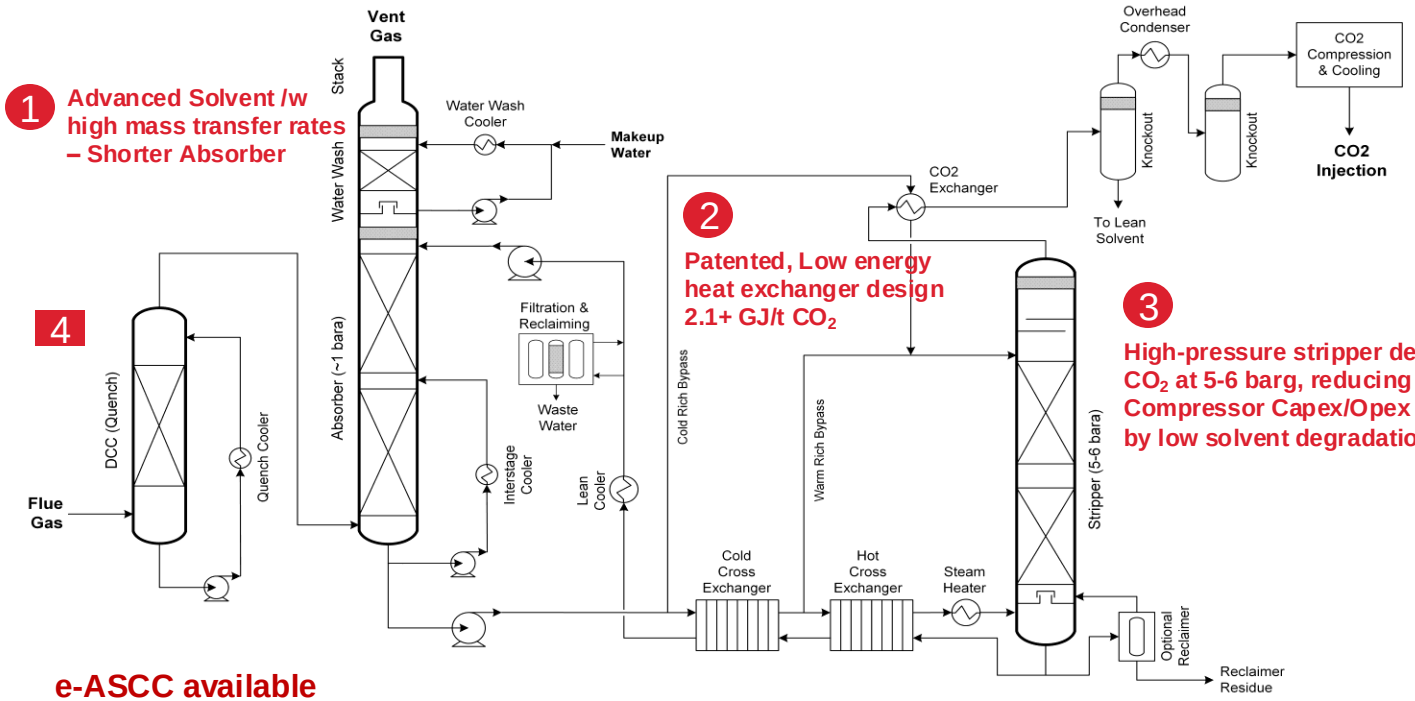


Enabling carbon capture with multiple technology portfolio

ADVANCED SOLVENT CARBON CAPTURE (ASCC)

HONEYWELL'S NEXT GEN SOLVENT TECH
ADVANCED SOLVENT CARBON CAPTURE (ASCC)

1 Advanced Solvent /w high mass transfer rates – Shorter Absorber



e-ASCC available

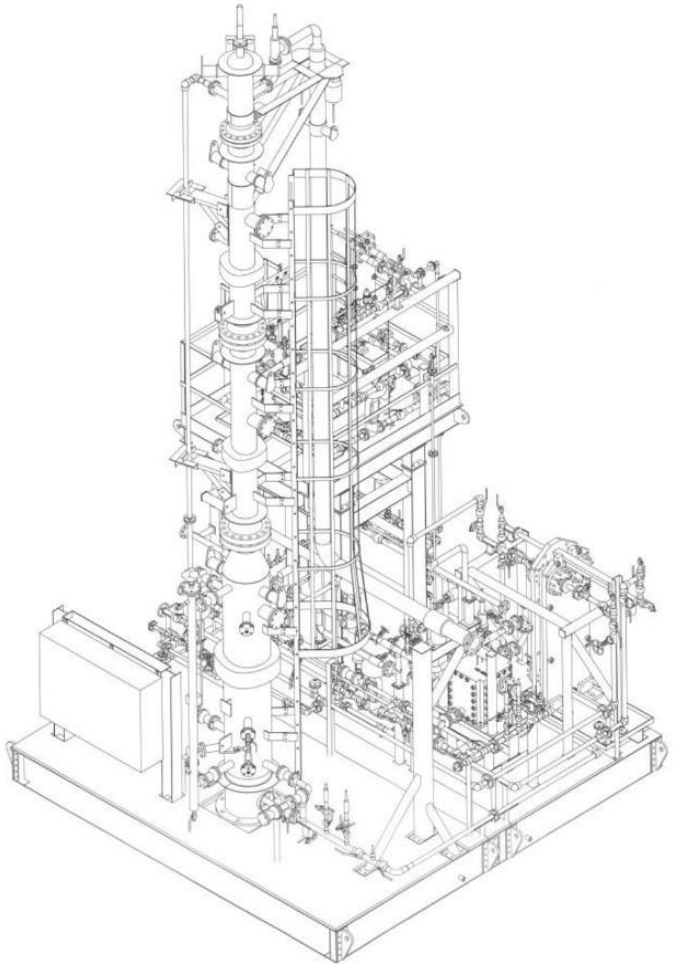
	Advanced	Prior Generation
Solvent Replacement Rate (kg/t CO_2)	<0.1 - 0.5	0.8 - 4.0
Heat Duty (OPEX) (GJ/t CO_2)	1.8 - 2.4	3.3 - 3.7
CO_2 Product Quality	>99.9%	>99%
Capture Rate	>95%	80-90%

Honeywell's ASCC is more efficient due to the high transfer rate of the solvent, lower energy needs, and low solvent degradation

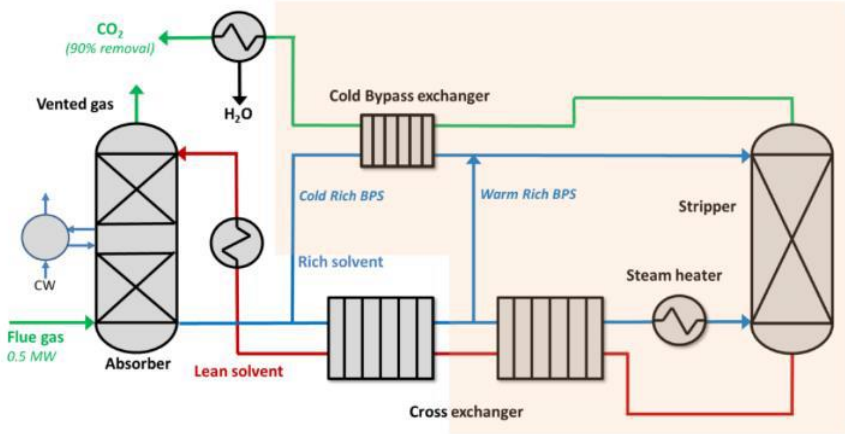
1. Higher mass transfer rate of solvent leads to capex savings from shorter absorber tower
2. Efficient heat exchanger integration leads to lower opex for regenerating solvent
3. Higher pressure regenerator/stripper means reduction in capex and opex for CO_2 compression train
4. Potential Elimination of DCC

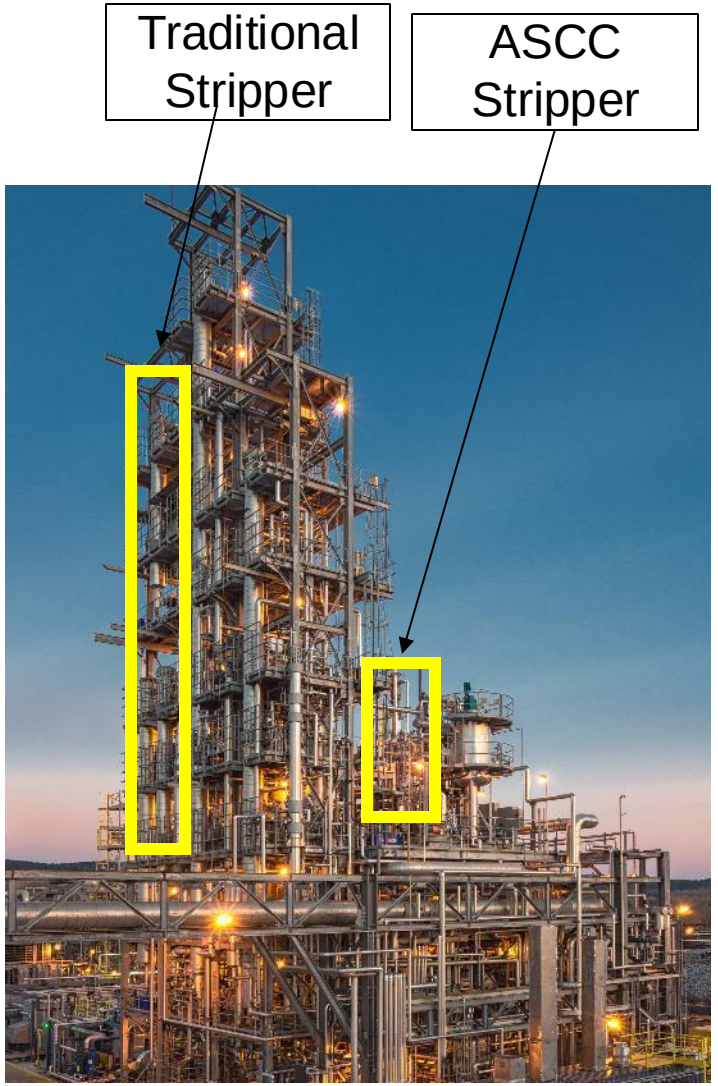
Current Solvent Gen reduces cost of capture between $15 - $20/ton CO_2

ASCC EQUIPMENT FOR NCCC TESTING

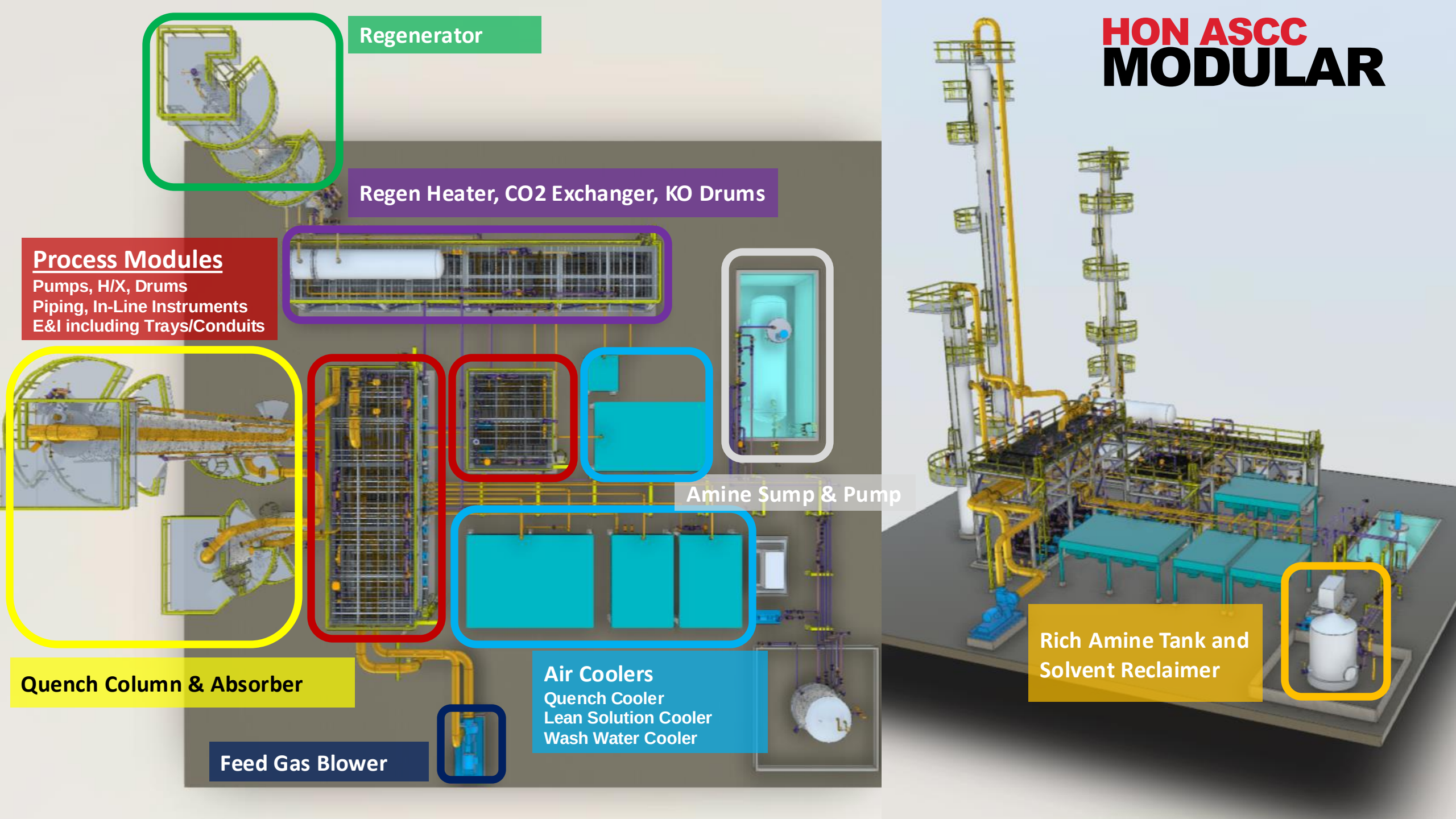


- NCCC demonstration utilizes existing absorber tower
- Purpose built skid with advanced flash stripper and heat exchange network installed at NCCC
- Verification of energy consumption and high pressure stripping
- Same solvent utilized for all three campaigns





Purpose Built Skid to Demonstrate Energy and Stripping Performance


Regenerator
Regen Heater, CO2 Exchanger, KO Drums
Process Modules
Pumps, H/X, Drums
Piping, In-Line Instruments
E&I including Trays/Conduits
Amine Sump & Pump
Quench Column & Absorber
Air Coolers
Quench Cooler
Lean Solution Cooler
Wash Water Cooler
Feed Gas Blower
HON ASCC
MODULAR
Rich Amine Tank and
Solvent Reclaimer

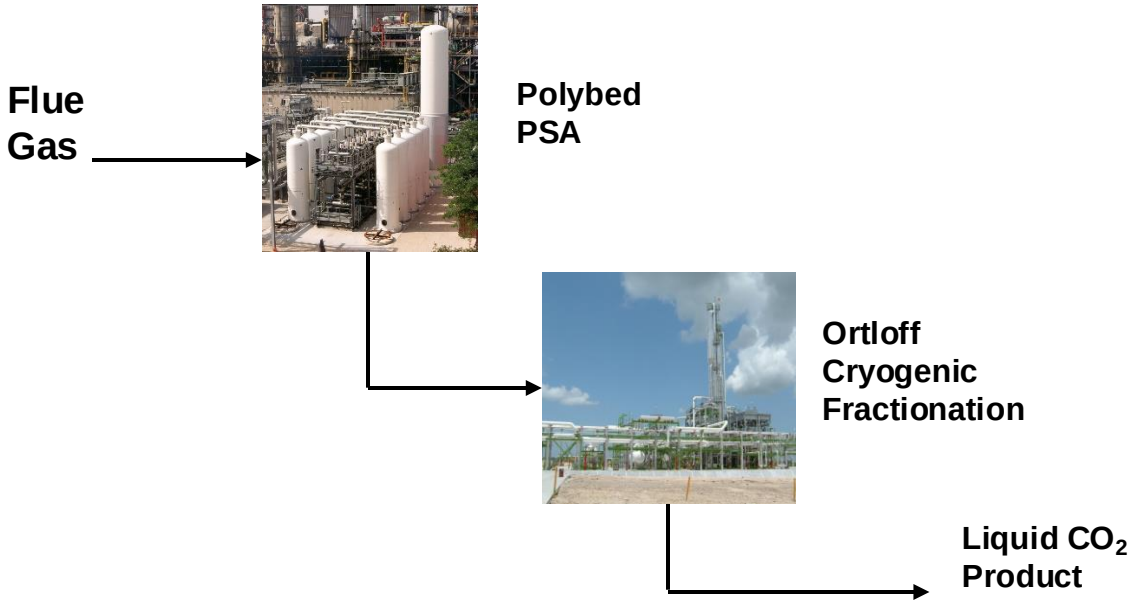
HONEYWELL RECENT CARBON CAPTURE EXPERIENCE

Year	Customer	Technology	HONs Role	Status	Industry	CO_2 Concentration	Annual CO_2 Capture, MMtpa	CO_2 Capture Rate
2021	Wabash	E&P + Licensor H_2 Purification + CO_2 Capture	CO_2 Frac	FEED complete	Hydrogen	>20%	1600	>95%
2022	PTTEP - Co2 Capture	E&P + Licensor Membrane System	Membrane	Start Up imminent	Natural Gas	>60%	1400	>95%
2023	XOM Baytown	E&P + Licensor H2 Purification + CO_2 Capture	CO_2 Frac	In FEED	Hydrogen	>20%	7000	>99%
2023	Mega Scale Low Carbon NH_3 Production	E&P + Licensor H2 Purification + CO_2 Capture	CO_2 Frac	In FEED	Ammonia	>20%	7360	>99%
2023	Duke	E&P + Licensor CO_2 Capture	ASCC	FEED Commencing	Coal Power	5.5%	3600	>95%
2022	Consol Energy	Licensor CO_2 Capture	ASCC	SOLD Pre-FEED complete	Coal Power	>9%	3100	>95%
2023	SK E&S	E&P Modular CO_2 Capture	ASCC	SOLD FEED	NGCC Power	4.2%	3	>95%
2023	Honeywell Geismar	E&P Modular CO_2 Capture	ASCC	FEED Commencing	Boiler Flue Gas	9.2%	85	>95%
2023	NAM - California	E&P + Licensor CO_2 Capture	ASCC	FEED Commencing	H2 SMR Flue	14%	245	>95%
2024	Calpine Energy	E&P + Licensor CO_2 Capture	ASCC	FEED Commencing	NGCC Power	4.1%	1750	>95%
2024	Crescent (Entergy)	E&P + Licensor CO_2 Capture	ASCC	FEED Commencing	NGCC Power	4.2%	3000	>95%

MYTHBUSTING KEY RISKS FOR PROJECT SUCCESS

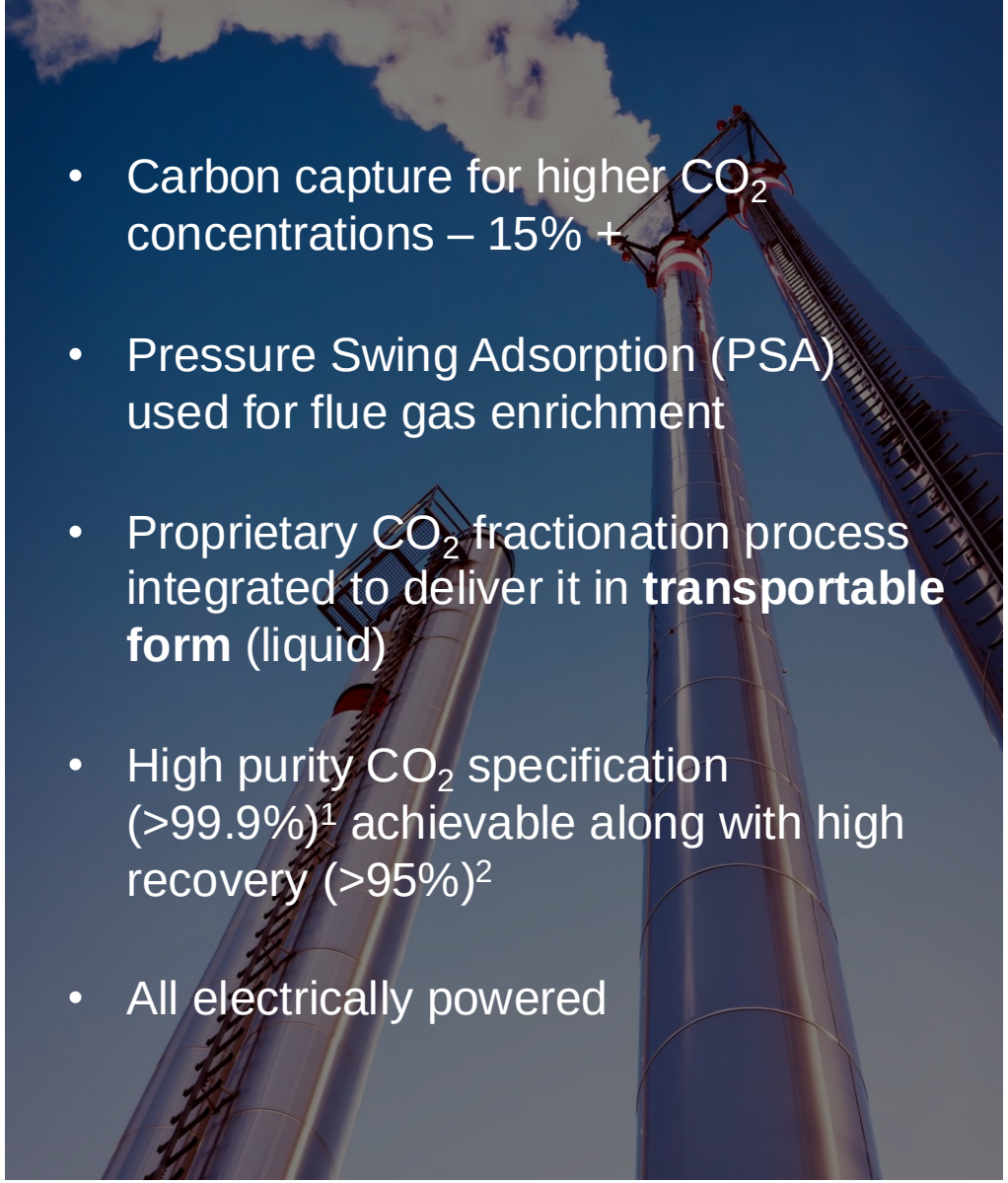
TOPIC	MYTH	REALITY	COMMENTARY
CAPTURE EFFICIENCY	• Amine tech will fail to achieve 95% capture rate for low-concentration CO_2	• Amine technology can achieve >95% capture rates	• Capture rate depends largely on contact area with the solvent; larger absorber increases capture rate
POST-COMBUSTION CARBON CAPTURE	• Solvent tech carbon capture is not compatible with flue gas from industrial sources	• Amine tech is well suited to capturing CO_2 off industrial flue gas; Several DOE FEEDs ongoing for deploying technology	• Cleaner burning fuel decreases contaminants; key is reducing NOx exposure
LARGE SCALE APPLICATION	• Success with small scale pilot testing does not mean success at large industrial scales	• Amine tech has been demonstrated at commercial scale for CC in the power sector	• Amine tech is deployed at commercial scale in other industries
BUILD COSTS	• Cost to build a project this large is not reasonably estimable without comparable projects	• EPCs are familiar with how to estimate & price equipment	• Required pieces of equipment are not inherently different from pieces used in other industries; fabrication costs are reasonably understood
OPERATING COSTS	• It is impossible to know the true cost to operate this technology at scale, and ongoing maintenance risks are high	• Amine units have been deployed in industry for >70years. Operators are familiar with these units and the major equipment within the unit.	• As demonstrated from our existing references, amine units at similar capacity have been deployed and therefore the cost of utilities can be estimated based on current equipment deployment.

CRYOGENIC CO_2 CAPTURE



Experience

- 1150+ PSAs in 9 different applications
- 418 cryogenic references in 5 different applications



- Carbon capture for higher CO_2 concentrations – 15% +
- Pressure Swing Adsorption (PSA) used for flue gas enrichment
- Proprietary CO_2 fractionation process integrated to deliver it in **transportable form** (liquid)
- High purity CO_2 specification (>99.9%)[1] achievable along with high recovery (>95%)[2]
- All electrically powered

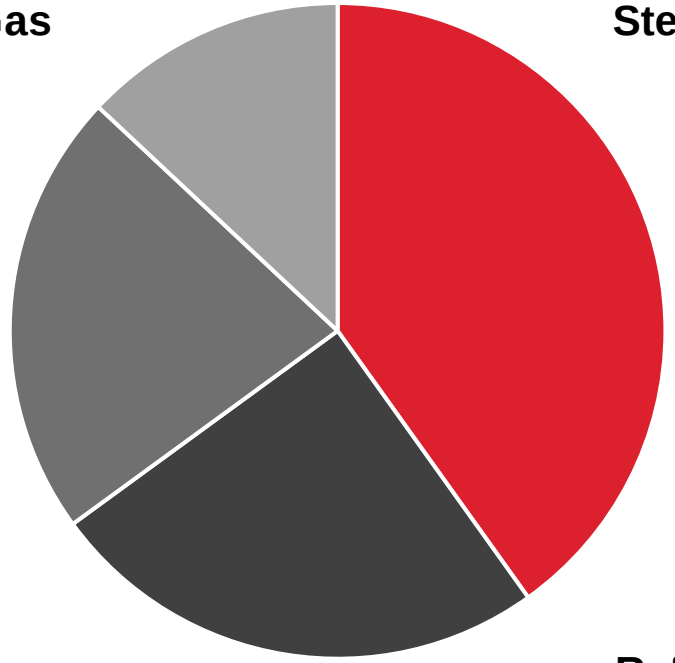
Energy Requirements Cryogenic Lower as CO_2 Concentration Goes Up

1. Based on Honeywell UOP PSASIM tool results for hydrogen purity level.
2. Based on internal study for cement flue gas.

HYDROGEN PSA APPLICATIONS & EXPERIENCE

13%
Ethylene Off-Gas
No. of Units: 151

40%
Steam Reformers
No. of Units: 465



22%
Specialty Applications
No. of Units: 255
- Ammonia Plants
- Coke Oven Gas
- Gasification
- Methanol Off-Gas
- Misc. Off-Gas
- Partial Oxidation / Syngas

25%
Refinery Streams
No. of Units: 255

>1,150 Polybed PSA units supplied by Honeywell UOP worldwide

CYRO: COMMERCIAL REFERENCES

Service	Highest Feed Flow, MMSCFD	# of Units
NGL Recovery	1,575	342
Refinery Off Gas	45	12
LPG Recovery	1450	49
LNG Production	10	10
CO_2 Capture	400	5
TOTAL		418

Total UOP Experience:
418 commercial references with unit capacity
up to 1575 MMSCFD

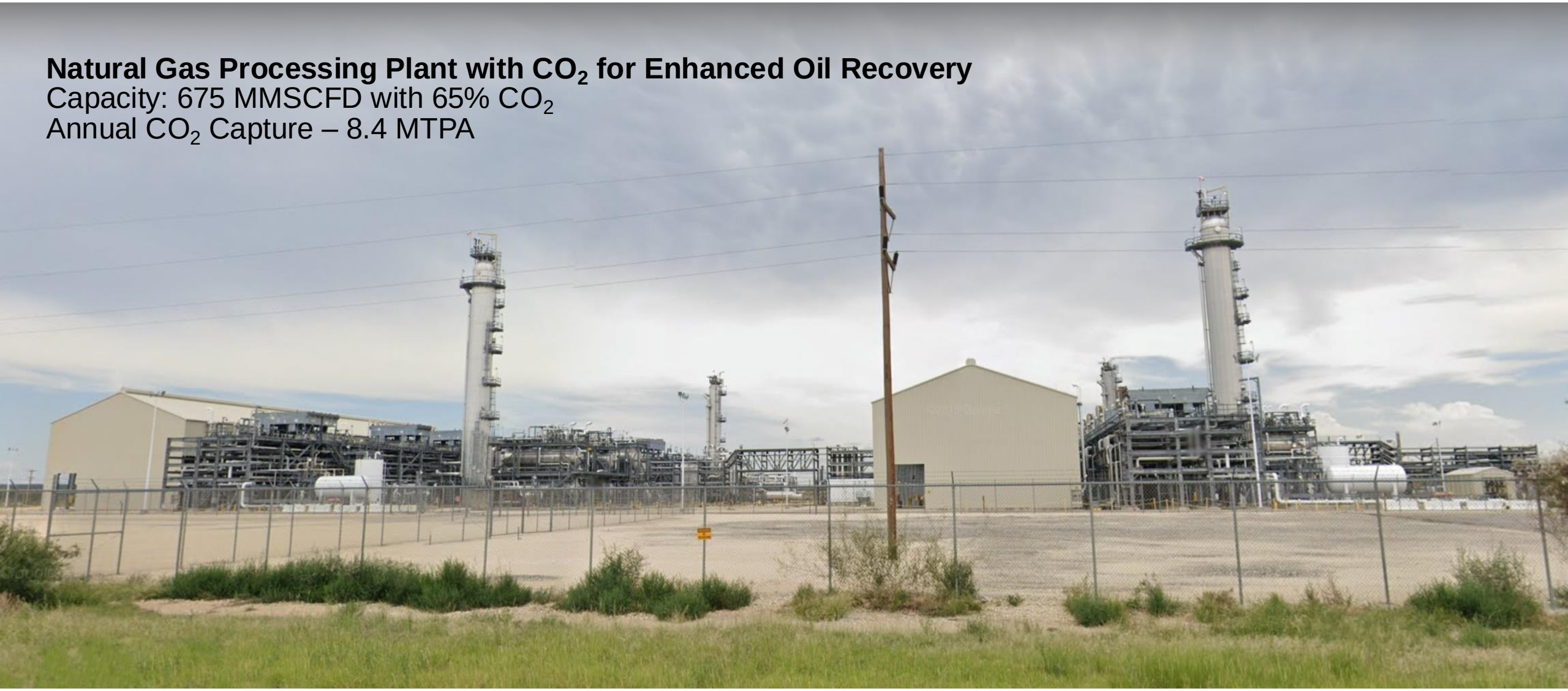
Service	Location	Captured CO_2, kMTPA	Engineering Completion
CO_2 FRAC	USA	8,400	Commissioned
CO_2 FRAC	USA		Commissioned
CO_2 FRAC	USA	1,650	2024
CO_2 FRAC	USA	7,000	2024
CO_2 FRAC	USA	6,700	2024

5 units in CO_2 capture service

Large scale experience in liquids recovery using fractionation technology

CO_2 FRACTIONATION UNIT | SANDRIDGE, TX USA

Natural Gas Processing Plant with CO_2 for Enhanced Oil Recovery
Capacity: 675 MMSCFD with 65% CO_2
Annual CO_2 Capture – 8.4 MTPA

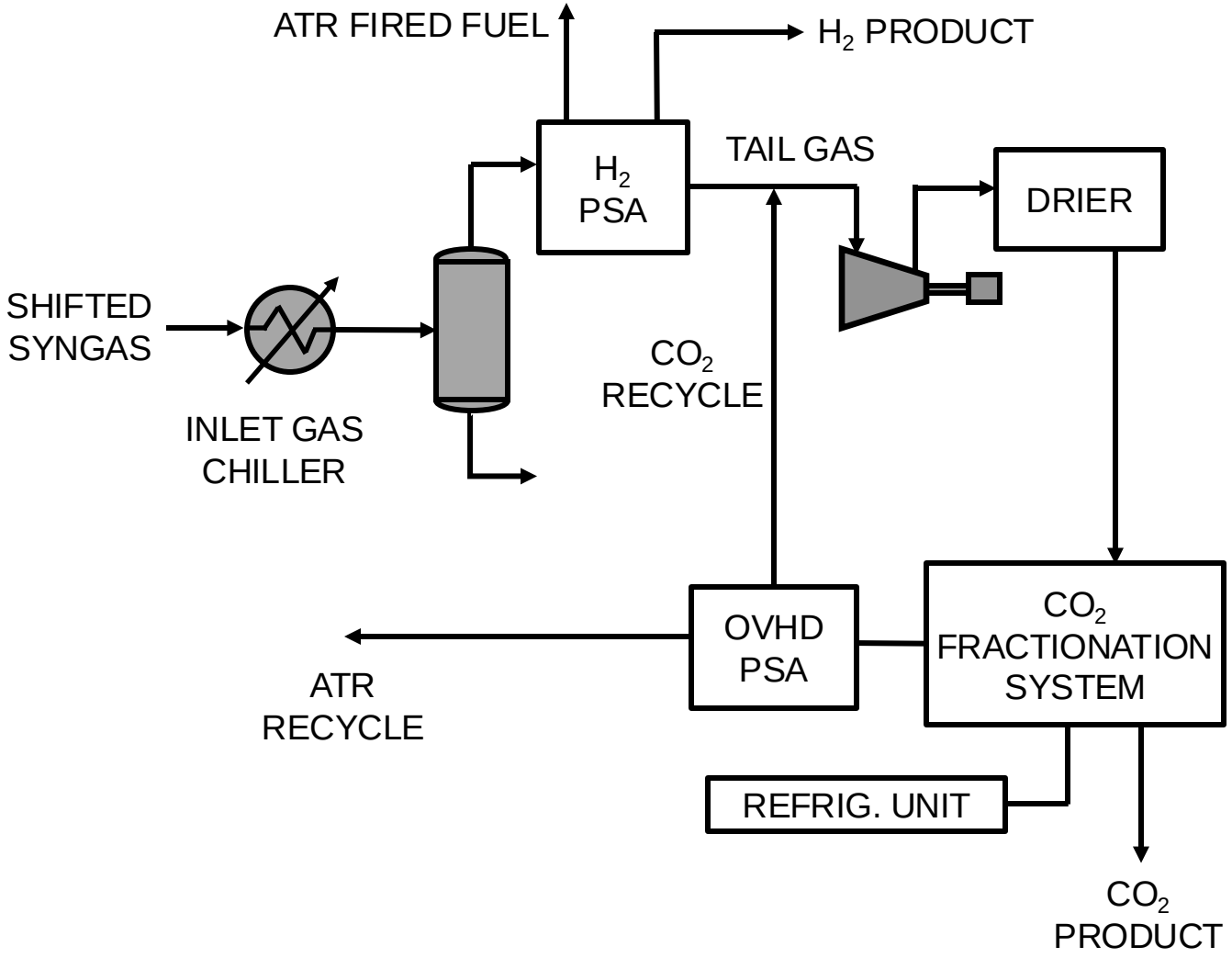


Reference Paper: Ross, F. P., and Cuellar, K. T., "Economical Option for CO_2 / Methane Separation in Produced Gas Containing a High CO_2 Fraction"

LOW CARBON H_2 – ATR SOLUTIONS

ATR RECYCLE LOW CARBON INTENSITY

UOP CO_2 FRACTIONATION SYSTEM



Off-gas Recycle to ATR Feed

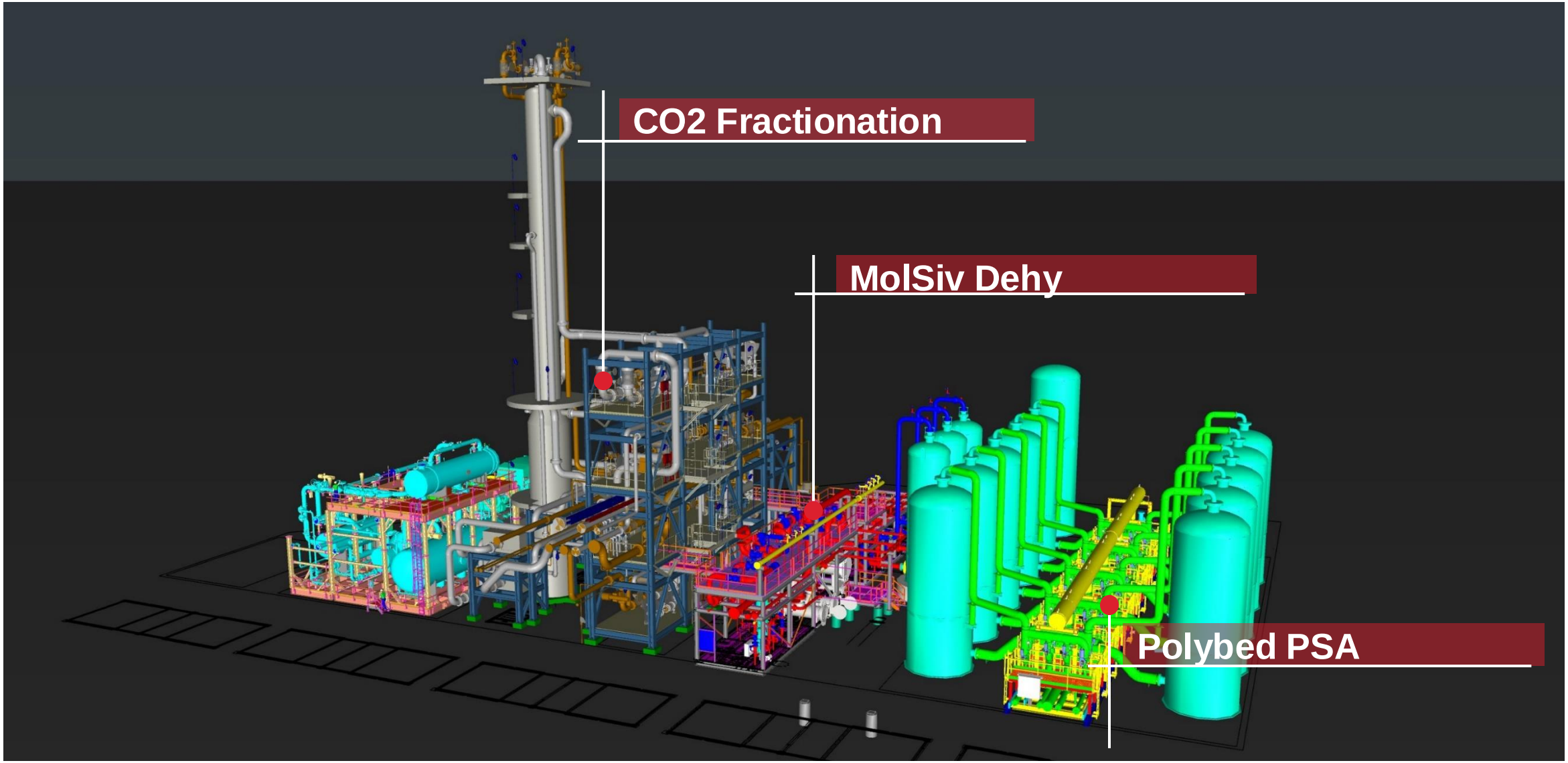
- Low Carbon Emissions
- Higher Feedstock Efficiency

Scope 1 Emissions: <0.1 kg CO_2 / kg H_2

Carbon-free fuel gas stream produced in H_2 PSA

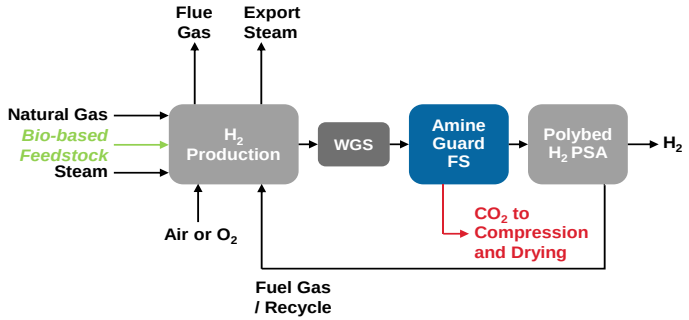
- Selective rejection of inerts
- Approximately 30 psi(g)
- Approximately 90 mol% H_2 and 10% N_2 + Argon

CO_2 FRACTIONATION UNIT

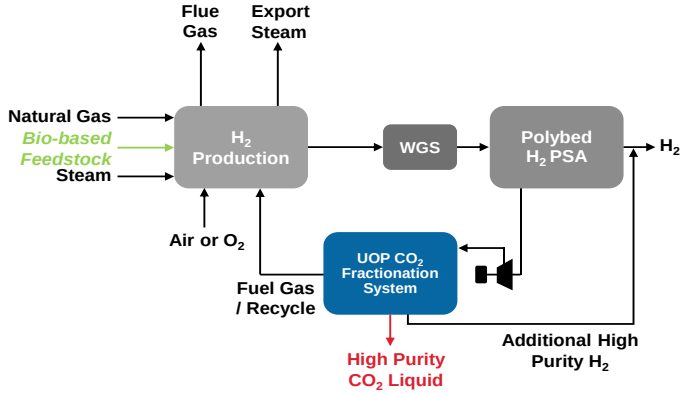


LOW CARBON H_2 – SMR RETROFIT SOLUTIONS

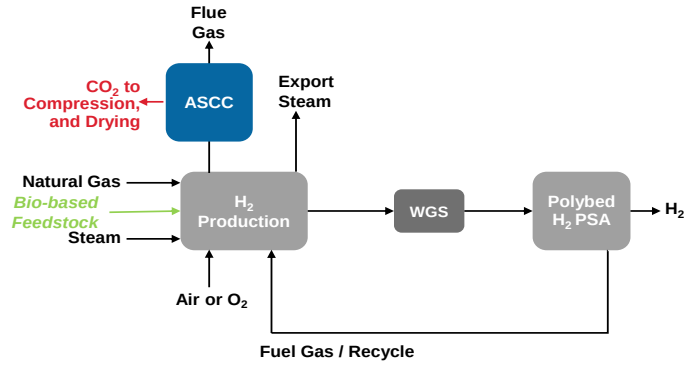
SMR CARBON CAPTURE OPTIONS



- Extensive Experience
- Lower Capex
- High Steam Usage
- Moderate Cost of Capture
- Requires PSA Revamp
- Lowers Operational Flexibility



- Significant Experience
- Lower Capex
- No Steam Required
- Lowest Cost of Capture (w/H2 credit)
- Bolt on, no PSA Revamp required
- No impact on Operational Flexibility

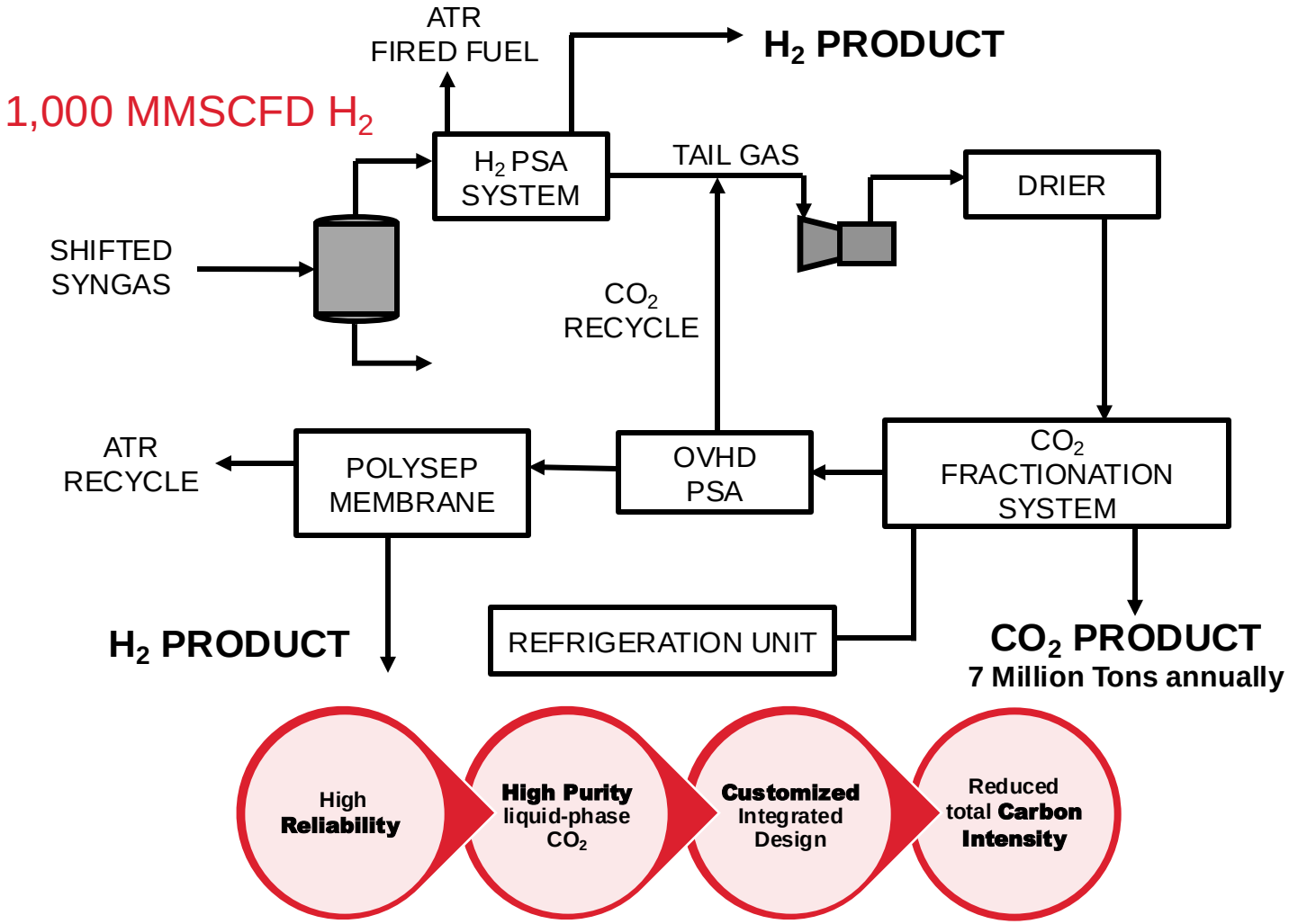


- First Commercial Commitments
- Moderate Capex
- Lower or No Steam Required (e-ASCC)
- Moderate Cost of Capture
- Bolt on, no PSA Revamp required
- No impact on Operational Flexibility

BLUE HYDROGEN CASE STUDIES

EXXONMOBIL CASE STUDY

UOP H_2 PURIFICATION AND CO_2 FRACTIONATION



CO_2 Fractionation System

- Enables the capture of about **7 million tons of CO_2 annually**, equivalent to the emission of 1.5 millions of automobiles for one year[1]
- **98% CO_2 emissions captured** across Low-Carbon Hydrogen production facility[2]

H_2 Purification

- **High Purity H_2 produced** from Pressure Swing Adsorption and Polysep™ Membrane technologies
- ExxonMobil's H_2 production project will enable **up to 30% of scope 1 and scope 2 emissions** reduced at their Baytown facility[3]

[1] Based on the EPA's GHG equivalency calculator comparing nearly 7 million tons of CO2 per year with gasoline-powered passenger vehicles on the road.

[2] CO_2 equivalent emissions is a calculated value based on the combined carbon compounds emitted from the Hydrogen production and Carbon Capture equipment plus the combined carbon compounds in the H2 product.

[3] Based on press release issued Feb 15, 2023, announcing HON H2 tech in Exxon Baytown facility. Link

CONCLUSION

1. Honeywell UOP has a portfolio of innovative carbon capture technologies, backed-up by decades of experience that offers industrial customers the opportunity to significantly reduce their emissions using proven technologies, including solvents and cryogenics.

2. For low carbon H2, UOP's cryogenic technology using the ATR solution is ideal solution (incl SMR retrofits)
   - Achieves extremely low process carbon intensity of <0.1 kg CO_2/kg H_2
   - All electric design allows potential for Scope 2 emissions reduction over time
   - H_2 product is at 99.9+% purity
   - Liquid CO_2 product stream is inherent to process and is ready for storage and shipping
   - Reliability: H_2 product supply can be delivered even when CO_2 capture system is shutdown
   - Equipment count of UOP Cryo fractionation system is about 2/3 that of an amine system

3. UOP cryogenic + PSA technologies demonstrating commercial viability
   - ExxonMobil Baytown blue H_2 project capturing 7 M mt/yr
   - Wabash Valley Resources B-NH3 project capturing 1.6 M mt/yr
   - Confidential B-NH3 project capturing 6.7M mt/yr

4. Initial applications of ASCC for SMR flue gas being contracted

The technologies to enable emission reduction are available today

THANK YOU

Honeywell
UOP