An economically attractive carbon capture solution for FCC

Reducing the cost of FCC carbon capture along with increasing FCC throughput and facilitating wider range feedstock processing

Jan de Ren, Sakthivelan Durai, Raul Zavala and Erick Bennet
Honeywell UOP

Refiners are facing increasing pressure to reduce the carbon (CO_2) intensity of their fluid catalytic cracking (FCC) units due to the ongoing energy transition and rise of environmental, social, and governance (ESG) initiatives. Refinery emissions contribute approximately 3% of the total anthropogenic Scope 1 and 2 carbon dioxide (CO_2) emissions, amounting to roughly 1,124 million tonnes per year (tpy).[1] Within FCC-based refineries, the FCC unit typically accounts for 15-25% of these emissions,[2,3] primarily stemming from the FCC regenerator. These emissions are a result of the coke burn operation required to maintain the unit's heat balance and restore catalyst activity.

Implementing post-combustion carbon capture in FCC units presents a three-fold challenge from an economic standpoint:

❶ The CO_2 concentration in the flue gas is low compared to pre-combustion applications.

❷ The volume of flue gas that requires treatment is substantial.

❸ The flue gas contains a notable amount of contaminants, necessitating significant upfront investment and continuous operating expenses for pretreatment. Pretreatment is required to prevent high solvent make-up rates in the downstream solvent-based carbon capture unit (CCU).

Honeywell UOP's proprietary Synthesized Air FCC technology offers several advantages, including reducing the cost of the FCC carbon capture step, enabling increased FCC throughput, and facilitating the processing of a wider range of feedstocks. This encompasses not only conventional feedstocks but also opportunity feeds, bio-renewable feeds driving sustainability, and plastic-derived feeds driving circularity by partially converting to light olefins (typical precursor for polymer production). Synthesized Air FCC technology presents an avenue for refiners to enhance the CO_2 capture process in FCC units. By reducing costs, increasing throughput, and accommodating various feedstocks, this technology aligns with the industry's drive towards a more environmentally conscious and economically viable future.

Oxy-combustion principle and concept evaluation at a European refiner

The FCC process breaks low-value, long-chain hydrocarbon molecules into higher-value, smaller molecules. One of the major by-products of the cracking reactions is coke, which gets deposited on the catalyst surface, resulting in catalyst deactivation. To restore the catalyst activity, the coke on the catalyst is combusted in a regenerator, where the traditional FCC process uses air as oxidising media. Typical atmospheric air contains 78 mol% nitrogen (N_2), 21 mol% oxygen (O_2), 0.93 mol% argon (Ar), and other gases like carbon dioxide (CO_2), carbon monoxide (CO), and neon (Ne) make up the rest.[4] For simplicity, air is composed of 4 moles of N_2 for every mole of O_2. The O_2 is consumed

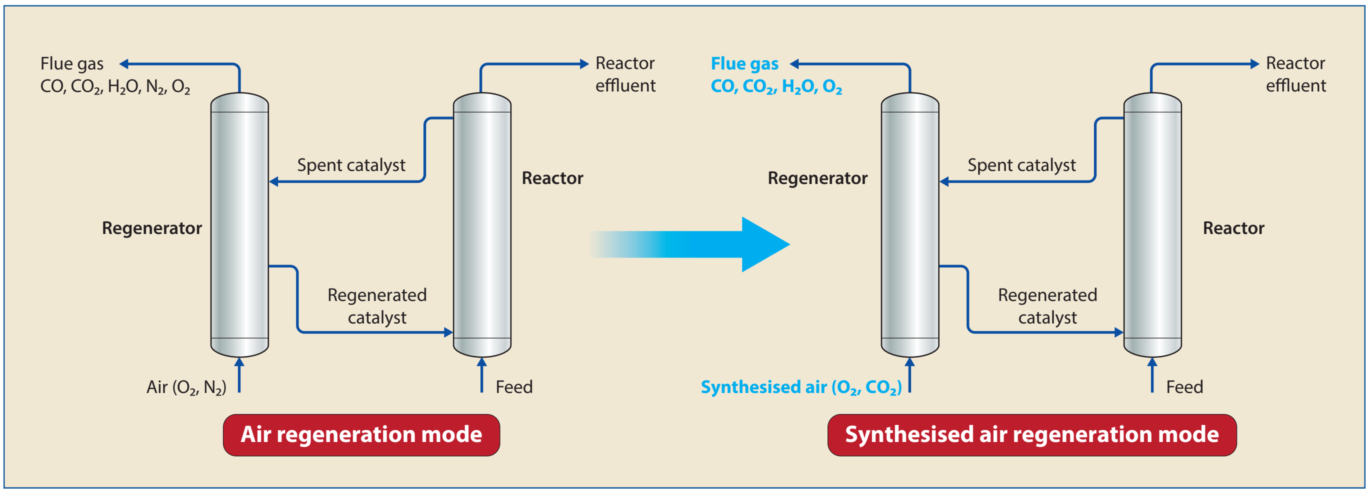

Figure 1 Air regeneration vs synthesised air regeneration

q4 Honeywell - Copy.indd 19
12/09/2023 13:14:09

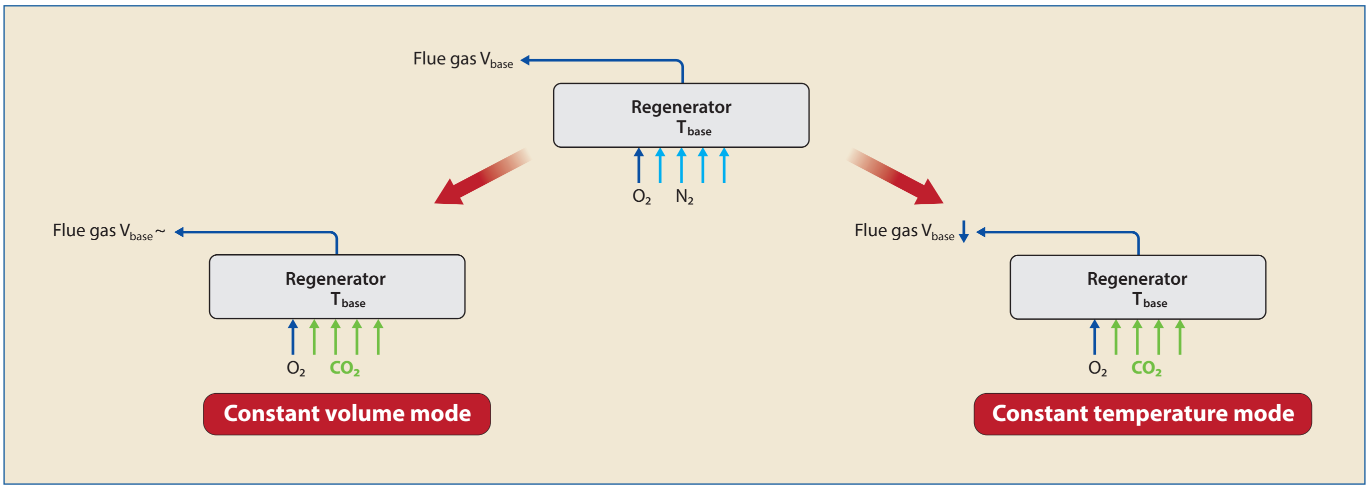

Figure 2 Constant volume vs constant heat balance/temperature mode of operation

by the combustion process in the regenerator, whereas N_2 remains inert and carries a substantial amount of heat released during the combustion process. This heat is typically recovered to a large extent in the flue gas heat recovery section of the FCC process.

In an 'oxy-combustion' (referred to as 'synthesised air' going forward) mode of operation, the combustion is facilitated by synthesised air, which is a mixture of O_2 and CO_2. The CO_2 replaces N_2 as the inert heat carrier to avoid excessively high temperature in the regenerator, as per **Figure 1**.

In the simplest form of synthesised air operation, every mole of N_2 in the air is replaced with an equal mole of CO_2. This results in the number of moles of regenerator flue gas remaining the same as typical air operation. Hence, the critical velocities in the regenerator, including vessel superficial velocity and cyclone velocity, can be maintained in a similar manner to base air operation. This is the ideal 'constant velocity operation' in synthesised air operation.

> **In the simplest form of synthesised air operation, every mole of N_2 in the air is replaced with an equal mole of CO_2**

The complexity of synthesised air operation arises from the fact that the molecular weight of CO_2 is approximately 1.6 times that of N_2. Due to higher molecular weight and consequent higher mass flow, heat carried away by CO_2 will be significantly higher for the same moles of N_2, which results in a substantial drop in regenerator temperature (assuming reactor temperature and feed quality are held constant). To achieve a 'constant heat balance operation' of the regenerator, the number of moles of CO_2 in synthesised air operation needs to be reduced without compromising the critical velocities. See **Figure 2** for a pictorial representation.

UOP performed a case study in 2023[a] on the application of Synthesized Air FCC system for a European refiner operating its FCC unit at a feed throughput of 65,000 BPSD, with nearly 75% residue in the feed blend. The blended feed Conradson Carbon (CCR) concentration of the feed was 3.6 wt% (see 'Case Study' section).

Based on the findings of this case study, conversion from normal air combustion to synthesised air operation is estimated to reduce the regenerator temperature from 738°C to 709°C. The drop in regenerator temperature and the reduced flue gas flow rate create additional coke burn capacity in the regenerator. This additional coke burn capacity provides an opportunity to increase residue content in the feed blend from 75% to 100%. The resulting regenerator temperature for this operation was estimated to be 738°C, like the base case. The results of the 2023 case study produced by Honeywell UOP proprietary process models demonstrate the inherent potential of its Synthesized Air FCC technology to increase FCC profitability, apart from reducing direct CO_2 emissions (Scope 1) via an installed CCU, as shown in **Figure 3** and detailed in the 'Case Study' section.

Process description

The principal components and general arrangement of the Synthesized Air FCC system are presented in Figure 3. It is comprised of a third-stage separator (TSS), power recovery turbine (PRT) section, heat recovery steam generator (HRSG), nViro FCC section, novel, proprietary, non-solvent Honeywell UOP FCC carbon capture section (CCS), and recycle blower. Note that an existing ESP/bag filter can be revamped to an nViro FCC unit, and a wet gas scrubber can be used in lieu of an nViro FCC unit.

Flue gas from the FCC regenerator enters the TSS, where separation of the larger catalyst fines from the flue gas stream is accomplished. The TSS provides the necessary particulate removal to protect the expander internals from blade deposition or erosion. The clean flue gas exiting the TSS flows to the expander for power recovery. The larger-sized catalyst fines, separated from the main flow of flue gas in the TSS, are carried out of the bottom of the TSS with a slip stream of flue gas. The larger-sized catalyst fines are removed from the slip stream via, for example, a fourth-stage separator (FSS) before the slip stream merges with the main flue gas line upstream of the HRSG. The expander

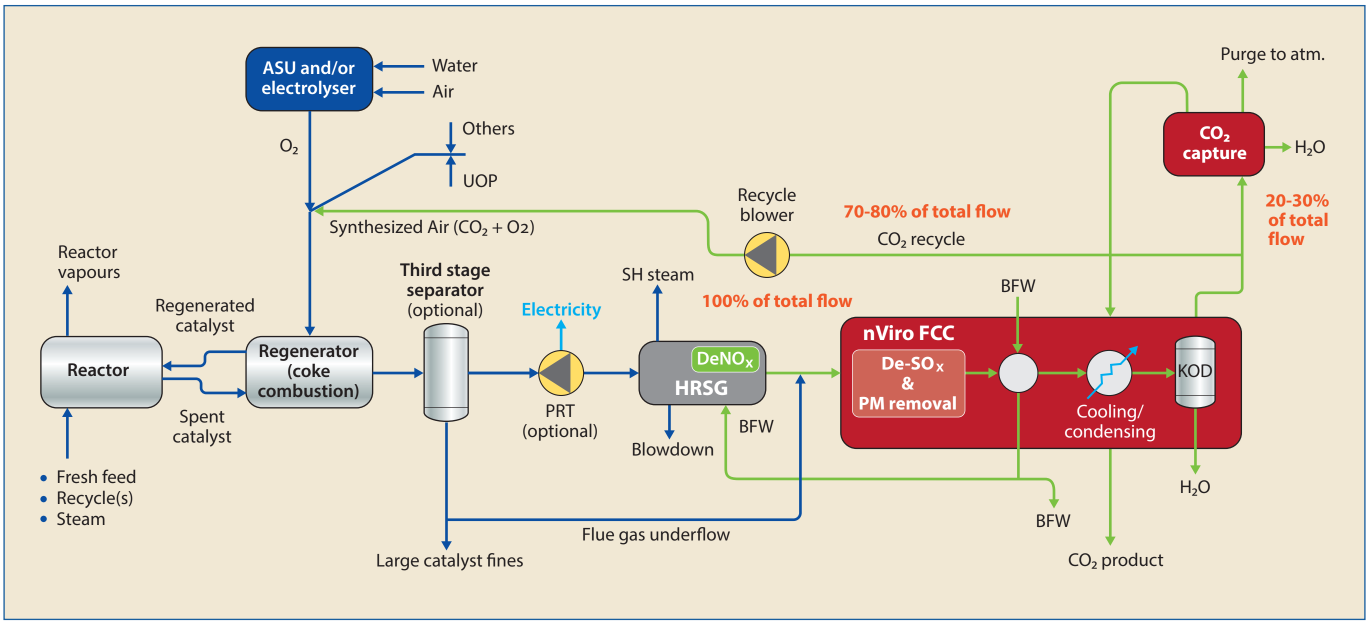

Figure 3 Honeywell UOP Synthesized Air FCC (indicated flow ranges highlighted in orange are typical ranges as determined by Honeywell UOP proprietary process models)

inlet valve will throttle to control the regenerator-reactor differential pressure. From the expander, the flue gas flows to the HRSG, where high-pressure steam is generated from the cooling of the flue gas stream. In some cases, provisions can be made to the HRSG to accommodate the removal of NOx contaminants. For units where HRSG cannot accommodate a NOx removal system, the same can be designed as part of the nViro FCC system or wet gas scrubber.

After the HRSG, the flue gas stream flows into the nViro FCC section. Here, the flue gas stream is treated for SOx and residual particulate matter contaminants. After this treatment, water is partially removed[b] to minimise the water concentration in the flue gas, followed by splitting the flue gas into two streams. Water removal prevents undesirable impacts (hydrothermal deactivation) of FCC catalyst.

The first stream flows to a recycle blower, where it is compressed and then combined with a high-purity oxygen stream. The high-purity oxygen is typically provided by an air separation unit (ASU) or electrolyser. The recycled flue gas, along with the high-purity oxygen, forms the synthesised air, which is then recycled back into the regenerator for the combustion of coke. The second stream flows to the Honeywell UOP FCC carbon capture section.

In this section, flue gas is treated and processed to recover the CO_2. The CO_2 separation technology is designed to achieve the desired product CO_2 temperature and pressure conditions as well as the desired phase: liquid, gas, or dense. Since a CO_2-rich stream in the form of synthesised air is used for FCC catalyst regeneration, the flue gas stream from the FCC unit concentrates to a CO_2 level of 90 mol% or more after partial water removal.[b,c]

Water is the bulk contaminant in the flue gas to the carbon capture section and is removed to achieve a higher purity CO_2 stream. The high-purity CO_2 stream is sent to further separation steps to remove additional contaminants, such as oxygen, to meet the required CO_2 purity of CO_2 product stream.

Synthesized Air FCC as an enabler for CO_2 utilisation

Once the CO_2 has been captured (see **Table 1**) and purified, per **Figure 4**, multiple CO_2 utilisation pathways are unlocked, such as blue and green MeOH and SAF, in addition to CO_2 electrolysis and mineralisation. Findings by IHS Markit and the CO_2 Capture Project, respectively, show that FCCs are among the largest CO_2 emitters in a refinery.[2,3] In this regard, as shown below in sections 'Key advantages of Synthesized Air FCC' and 'Case study', Honeywell UOP

> **Once the CO_2 has been captured and purified, multiple CO_2 utilisation pathways are unlocked, such as blue and green MeOH and SAF, in addition to CO_2 electrolysis and mineralisation**

Synthesized Air Technology could be a key enabler for: i) carbon (CO_2) intensity reduction of refining operations; ii) blue and green fuel/chemicals production; iii) continued FCC operation in a low(er) carbon intensity future.

Key advantages of Synthesized Air FCC

- Helps increase the concentration of CO_2 in flue gas from the typical 15 ~ 20 mol% to more than 80 mol%.[d] This provides an opportunity to adopt a lower Capex/Opex CCU to produce a high-purity CO_2 product stream and eliminate the requirement for solvent-based carbon capture technologies.
- Eliminates concerns relating to solvent degradation[9] and replacement by using CO_2 capturing technologies that do not require solvents.
- For an existing regenerator converted to synthesised air

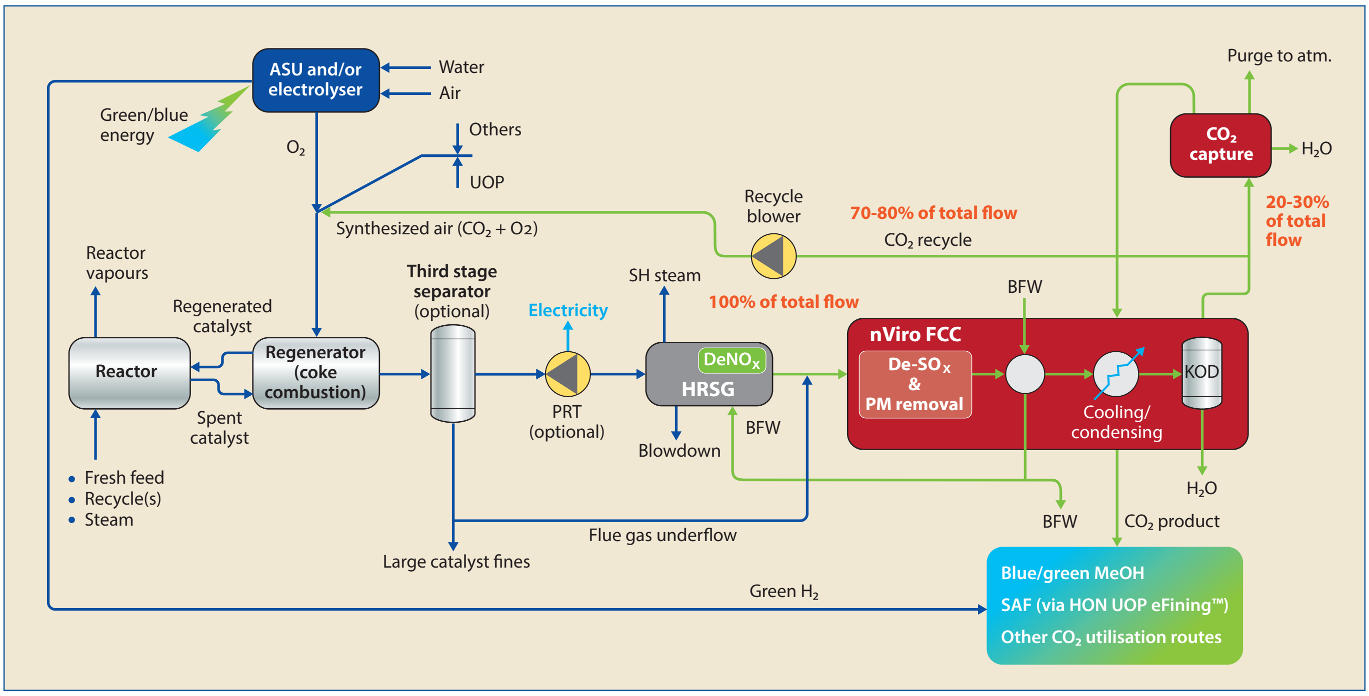

Figure 4 Honeywell UOP Synthesized Air FCC enables several CO_2 utilisation pathways

operation, the drop in regenerator temperature and flue gas volumetric flow unlocks additional coke burn capacity in the regenerator. This feature can be leveraged by increasing the reactor coke make, which provides the opportunity to increase the residue component in the feed blend. Alternatively, the possibility of increased coke burn capacity in the regenerator provides an opportunity to increase the feed processing capacity of the FCC unit up to 30%, provided the reactor and downstream separation system can handle the additional flow rate.[d]

- The large (70-80 mol%) flue gas recycle for the synthetic air FCC units results in less Capex and Opex required for the CO_2 capture system since it can be smaller due to only processing 20-30 mol% of the total flue gas.
- The main utility required in the CCU is electricity as compared to steam in traditional solvent-based CCUs to regenerate solvent in the stripper section.
- For a new FCC unit, the higher molecular weight of CO_2 enables a size reduction of the regenerator and flue gas section.
- If nViro FCC is included in the flow scheme, the heat recovery from the flue gas stream can be increased, leading to improved process energy efficiency.
- Can enable more bio-renewable feed co-processing (O_2- rich feedstocks) due to the larger heat sink in the regenerator. Note that processing bio-renewable feedstocks, due to higher feed oxygen content, can result in more coke to the FCC regenerator, thereby increasing the FCC regenerator temperature. The mechanism behind this higher coke level is a deoxygenation pathway consuming hydrogen to produce water ($H_2 + O_2 \rightarrow H_2O$), resulting in reduced hydrogen availability, which can result in higher coke make[5,8] and subsequently higher regenerator temperatures. Having a larger heat sink in Synthesized Air FCC when operating in 'constant volume operating mode', one will be able to process more biogenic feedstock without running into regenerator temperature constraints.
- Represents a carbon capture complex with a positive return on investment without having to rely on any form of CO_2 reduction incentives/tax due to the ability to process more feed and/or more opportunity feedstock, as per Table 1.
- Use of typical hydrocarbon refrigerant(s) (such as propane) in refineries.

Carbon capture options enabled by synthesised air mode of FCC catalyst regeneration mode

CO_2 capture is achievable in both traditional air combustion[10] and Synthesized Air FCC units. For traditional air

Simple payback with Honeywell UOP Synthesized Air FCC with 20% higher coke burn

Simple payback	Reduced feed costs	Increased yields	Utilities/oxygen*	Carbon credit	Payback
		Additional 20% coke burn (alternate feed blend)			
$0/t Carbon Credit	$51.8 MM/yr	N/A	$28.3 MM/yr	$0 MM/yr	4.8 yrs
$50/t Carbon Credit	$51.8 MM/yr	N/A	$28.3 MM/yr	$19.2 MM/yr	2.7 yrs
$100/t Carbon Credit	$51.8 MM/yr	N/A	$28.3 MM/yr	$38.4 MM/yr	1.8 yrs
$150/t Carbon Credit	$51.8 MM/yr	N/A	$28.3 MM/yr	$57.6 MM/yr	1.4 yrs

*Oxygen concentration in synthesised air stream to regenerator is 21.5 – 22 mol%.

Table 1

combustion FCC units, solvent technology is often the preferred method of CO_2 capture due to the low CO_2 concentration in the flue gas and overall low partial pressure of CO_2. Advanced solvents, like those used in Honeywell UOP's Advanced Solvent Carbon Capture (ASCC) technology, are required for effective CO_2 capture. O_2 levels in the flue gas feed to solvent-based CCUs with amine-type solvent are to be kept low to prevent solvent degradation.[7]

Switching to Synthesized Air technology in the FCC unit results in a significantly higher CO_2 concentration than in traditional air combustion FCC units: >80 mol% CO_2 on a wet basis as contrasted with 15-20 mol% CO_2 in the flue gas stream. This higher CO_2 concentration unlocks CO_2 capture options for technologies outside of solvents. Solvents are a potential technical fit for synthetic air combustion. However, they are not the most economic technology selection, as their benefits diminish at higher CO_2 concentrations in the flue gas stream. Other CO_2 separation/purification technologies are more economically viable in the synthetic air combustion case for FCC.

One such CO_2 separation option is a cryogenic separation unit. When paired with inlet compression and a dehydration unit, the cryogenic separation unit enables high recovery of CO_2 in either a single pass or recycle flow scheme while also meeting stringent CO_2 specifications (high product purity), such as low O_2 content in the product CO_2 stream due to the high CO_2 inlet partial pressure. The single pass or recycle flow scheme is determined based on oxygen content in the cryogenic unit overhead and economics around the price of the lost O_2. The CO_2 fractionation system can be optimised for the temperature, pressure, and phase requirements of the CO_2 product stream.

> **When paired with inlet compression and a dehydration unit, the cryogenic separation unit enables high recovery of CO_2 in a single pass or recycle flow scheme**

Synthesized Air FCC technology does have challenges compared to traditional air combustion. This includes requiring high-purity O_2 (>90 mol%)[6] from an electrolyser or ASU and the additional equipment and electricity costs associated with the recycle loop blower. Ultimately, an economic analysis considering both Capex and Opex of the CO_2 separation equipment savings vs the additional cost of recycle equipment, such as the comparison in the following case study, needs to be performed to evaluate the potential benefit of the technology for a refiner.

Case study

UOP performed the following study in 2023 to assess the potential of its Synthesized Air FCC technology for CO_2 emissions reduction and increased profitability of operating FCC units. A European refinery with a 37,500 BPSD UOP FCC was looking into reducing Scope 1 and 2 emissions driven by carbon reduction policies/incentives/mandates in the European Union. A major challenge with carbon reduction technologies is implementing an economically viable solution without assistance from carbon reduction policies/incentives.

Honeywell UOP assisted the refiner by analysing the value delivered by introducing Synthesized Air FCC technology into their current operations. Its technology was proposed as a solution to accomplish cost-effective, post-combustion carbon capture with the expectation that the refiner is going to utilise the CO_2 as a feedstock source to generate revenue downstream of the FCC rather than sequestring.

With a tailor-made Synthesized Air FCC operation, Honeywell UOP estimated that an additional 20% coke-burning capacity in the regenerator is achievable. The additional coke burning capacity allows for the blending of less expensive, lower-quality (higher CCR) feed to the FCC unit. This alone is estimated to generate an economic return of about $50 million per year. This result is based on the assumption of applying 2023 Western European feed and product pricing:

Hydrotreated AR W Europe:661.30 $/t	Fuel gas: 494.88 $/t
High sulphur VGO (2 wt% S): 727.39 $/t	LCO: 958.25 $/t
Propylene W Europe: 1518.4 $/t	Slurry oil: 716.18 $/t
Full-range naphtha: 920.45 $/t	

Pricing is based on Honeywell UOP proprietary pricing methodology, LP modelling having typical Honeywell UOP assumptions, and IHS Markit July 2022 feed and product pricing information.

The proposed Synthesized Air FCC configuration is depicted in **Figure 4**.

The cost of implementing the technology included a revamp of existing FCC equipment, new traditional FCC equipment, a new UOP nViro FCC section, and a new UOP FCC carbon capture section. Revamping the existing equipment includes revamping the flue gas steam generator for the greater mass flow of the CO_2-rich FCC flue gas along with a new recycle blower that would replace the existing main air blower of the FCC. The new nViro and carbon capture sections will require additional plot space and will be highly heat integrated within the flue gas system. The estimated erected cost (Class 5 level accuracy) of installing this equipment on a 37,500 BPSD FCC unit was approximately $100 million.

UOP estimated that with an additional 20% coke burning capacity in the FCC regenerator, the refiner would be able to blend in up to 50% of FCC feed with a lower quality (higher residue feed) at a constant total throughput of 37,500 BPSD. This blending arrangement gives the refiner an estimated feed cost reduction of about $50 million per year ($1MM per 1% blended feed). With oxygen at a cost of $50/t and consumption equivalent to 21.5 ~ 22 mol% O_2 in synthesised air, the annual expense of oxygen is estimated to be $19 million.

The other operational expenses for this technology update were estimated at $9 million per year,[11] based on a 37,500 BPSD FCC.[e]

This includes $33 million per year in operating expenses on the nViro FCC and carbon capture sections while

Simple payback with Honeywell UOP Synthesized Air FCC, with 20% increased feed throughput					
Simple payback	Reduced feed costs	Increased yields Increased 20% throughput	Utilities/oxygen*	Carbon credit	Payback
$0/t carbon credit	N/A	$53.5 MM/yr	$31.3 MM/yr**,#	N/A	4.3 yrs

*Oxygen concentration in synthesised air stream to regenerator is 28 mol%.
**20 MMBTU/hr of additional thermal energy is needed to close FCC heat balance, as opposed to cases in Table 1.
Additional utilities for downstream processing of additional products not included; utilities considered for Synthesized Air FCC only.

Table 2

saving $24 million per year through improved energy harvesting. The nViro FCC helps recover an additional 21 MMBtu/hr of heat from the flue gas. Processing an advantaged feedstock together with improved system energy efficiency results in an opportunity to generate revenue on this investment that would otherwise be a simple expense. Additionally, any tax incentives/carbon credits/ government funding would make this investment even more profitable for the refiner, as shown in Table 1.

As an alternate strategy, the additional 20% coke burning capacity in the FCC regenerator can be translated into 20% incremental feed processing in the FCC unit. This is estimated by Honeywell UOP to result in additional product realisation of $54 million per year. With oxygen at a cost of $50/t[11] and consumption equivalent to approximately 28 mol% O_2 in synthesised air, the annual expense of oxygen is estimated to be $19 million. The other operational expenses for this technology update were estimated at $12 million per year, based on a 37,500 BPSD FCC.[e] This includes $29.5 million per year operating expenses on the nViro FCC and carbon capture sections while saving $17.5 million per year through improved energy harvesting. The simple payback estimate for this option is presented in **Table 2**.

A few considerations for equipment modifications that may be required due to increased throughput are:
- Reactor, stripper, and their internals need to be checked for increased velocity and catalyst flux.
- Main column heat balance needs to be reviewed and adjusted as required to compensate for the increased flow through the gas concentration unit.
- CO_2 concentration in the FCC reactor effluent and the FCC off-gas will increase, therefore water wash and amine rates in the respective sections should be assessed.
- Lastly, the capacity of the heat exchangers, pumps, and columns needs to be assessed.

Based on Honeywell UOP process modelling and applying the company's typical process design guidelines, it was determined that for the respective cases, installing a Synthesized Air FCC CCU would reduce FCC regenerator CO_2 emissions from 1,213 t/d to 61 t/d, considering a CO_2 capture efficiency of 95%.

Though the previous case studies considered an nViro FCC for flue gas treatment, Synthesized Air FCC technology is equally adaptable for units with existing wet gas scrubbers. With Synthesized Air FCC operation, the refiner can explore multiple pathways to increase the profitability of their existing FCC assets. They can leverage opportunity crudes, apply carbon credits where available, or increase throughput. The optimal utilisation of the technology may come from a single benefit or a combination of all three.

Conclusion

The performed studies have demonstrated that Synthesized Air FCC technology can offer refiners a flexible and economically viable carbon capture solution to future-proof operations. This innovative technology not only reduces Scope 1 emissions from the FCCs but also from the entire refinery because FCCs typically contribute 15-25% of the emissions.[2,3] Moreover, opportunities for synergies with electrolysers, ASUs, and pathways to produce future-oriented products such as green/blue MeOH and SAF, were identified. In other words, a glimpse of the potential future of FCCs has been provided.

Since the introduction of FCC technology more than 80 years ago, refiners have relied on their FCCs for their adaptability to stay relevant in the marketplace. With Synthesized Air FCC, the ability to co-process renewable and plastics-derived pyrolysis oil, and the shift to a high propylene mode of operations coupled with aromatics extraction, it becomes probable or perhaps even evident that FCCs will once again leverage their flexibility to thrive in this exciting era of energy transition.

References

1 Wood Mackenzie, *Refinery emissions: Implications of Carbon Tax and Mitigation Options*, Nov 2021.
2 IHS Markit, *Global Fundamentals Crude Oil Markets Prices Long-Term Outlook*, Third Quarter, 2021.
3 CO_2 capture project; project factsheet; oxy-firing Fluid Catalytic Cracking Demonstration (www.co2captureproject.org/reports/FACTSHEET_FCC.pdf), 2013.
4 L Dorazio, J Shi, James Fu, S S Ail, M J Castaldi, G Chowdhury, Co-processing renewable and recyclable feedstocks in the FCC unit, Catalysis 2022.
5 Nexant, *TechnoEconomics; Energy & Chemicals, Air Separation Technology*, Oct 2019.
6 ScienceDirect, S B Fredriksen, K-J Jens, Norner A S, *Oxidative degradation of aqueous amine solutions of MEA, AMP, MDEA, Pz: A review*, 2013.
7 C Avery, J Strohm, FCC pathways to co-processing, *PTQ*, Q4 2021
8 ScienceDirect, S A Bedell, *Oxidative degradation mechanisms for amines in flue gas capture*, 2009.
9 Frontiers in Energy Research, F Güleç, W Meredith, C E Snape, *Progress in the CO_2 capture technologies for fluid catalytic cracking (FCC) units – A Review*, 2020.
10 ACEEE Summer Study on Energy Efficiency in Industry, P Rao, M Muller, *Industrial Oxygen: Its Generation and Use*, 2007.

Notes

a In the course of the 2023 case study, UOP employed proprietary Honeywell UOP process models for developing the Heat & Mass balances based on first principles of Thermodynamics utilising Unisim Design suite, a kinetic model for modelling the combustion kinetics was used for estimating SOx, NOx, HCN, NH_3, CO, CO_2 in FCC flue gas, and a semi-empirical/kinetic model was used for yield estimating. Typical Honeywell UOP engineering assumptions and process design guidelines have been utilised.

b Determined with help of proprietary Honeywell UOP FCC process models, process design guidelines, and catalysis fundamentals.

c The 90 mol% is based on the results of proprietary Honeywell UOP process modelling conducted in 2023. It is expected that the flue gas is cooled to approximately 120°F to condense the water in the flue gas near atmospheric pressure.

d This is based on Honeywell UOP process modelling conducted in 2023 using proprietary models of FCC units. With no consideration for FCC heat balance requirements and possible constraints in the FCC reactor/fractionation/gas concentration section, FCC capacity can be increased by 30% by (i) having CO_2 with a molecular weight (MW) of 44 g/mole displace N_2 with an MW of 28 g/mole, and (ii) increasing O_2 content from 21 mol% to 28 mol%.

e The O_2 price is 50 \$/t, and equipment pricing is based on USGC. Utility pricing is 0.35 \$/kWh electricity, 124 \$/t of HP steam, and 19.92 \$/t of BFW. The FCC was operating in gasoline mode of operation. Power saving is 873 kWh (because of reduced blower load, recycle compressor in lieu of main air blower). There was an increase in steam generation (22 t/h) and BFW use (23 t/h) because of burning more coke.

Jan De Ren is Global Sr. Offering Manager for Honeywell UOP's Fluid Catalytic Cracking, Hydroprocessing and Heavy Oil technologies, responsible for all offerings in the existing portfolio and for commercialising next-generation offerings. He is based in Honeywell UOP's office in Des Plaines, Illinois, USA. He holds an MSc in applied chemical engineering from the University of Antwerp and 10 US patents.
Email: Jan.DeRen@Honeywell.com

Sakthivelan Durai is Fluid Catalytic Cracking Process Specialist for Honeywell UOP based out of Gurgaon, India. He specialises in the design of reactor regenerator systems for FCC units and has 20 years of experience in the refining and petrochemical industry. He holds a bachelor's degree in chemical engineering from the University of Madras and has a US patent.
Email: Sakthivelan.Durai@Honeywell.com

Raul Zavala is Principal Innovation Engineer for Honeywell UOP in Des Plaines. He specialises in engineering innovations for fluidised bed reactor technologies and has 12 years of experience in the refining and petrochemical industry. He holds a bachelor's degree in chemical engineering from the University of Notre Dame, a master's in business administration from St. John's University in New York City, and five US patents. *Email: Raul.Zavala@Honeywell.com*

Erick Bennett is Lead R&D Engineer for Honeywell UOP in Des Plaines, with 10 years of experience in the refining and petrochemical industry. He focuses on gas processing technologies, including the development of blue hydrogen and carbon capture technologies. He holds bachelor's and master's degrees in chemical engineering from the Northwestern University.
Email: Erick.Bennett@Honeywell.com