DECARBONIZING OLEFINS PROJECTS

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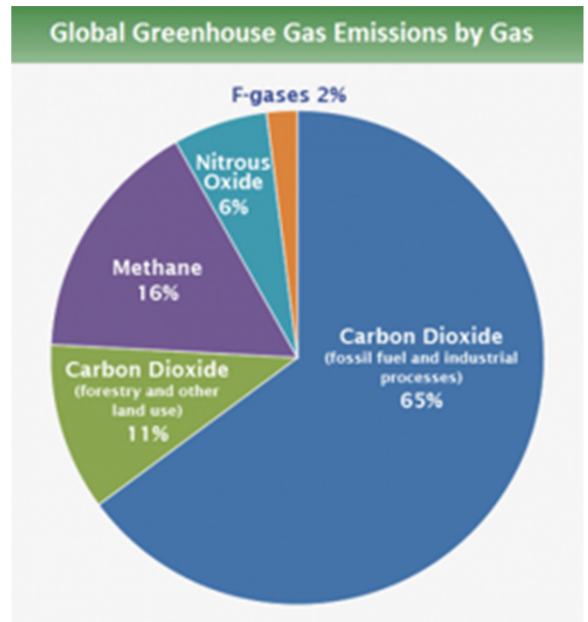
OLEFINS PRODUCTION – CO_2 EMISSIONS

- Steam cracking is the main industrial process to produce light olefins
- Steam cracking is the most energy consuming process in the chemical industry
- ~300 MM metric ton of CO_2 is produced from steam cracking each year

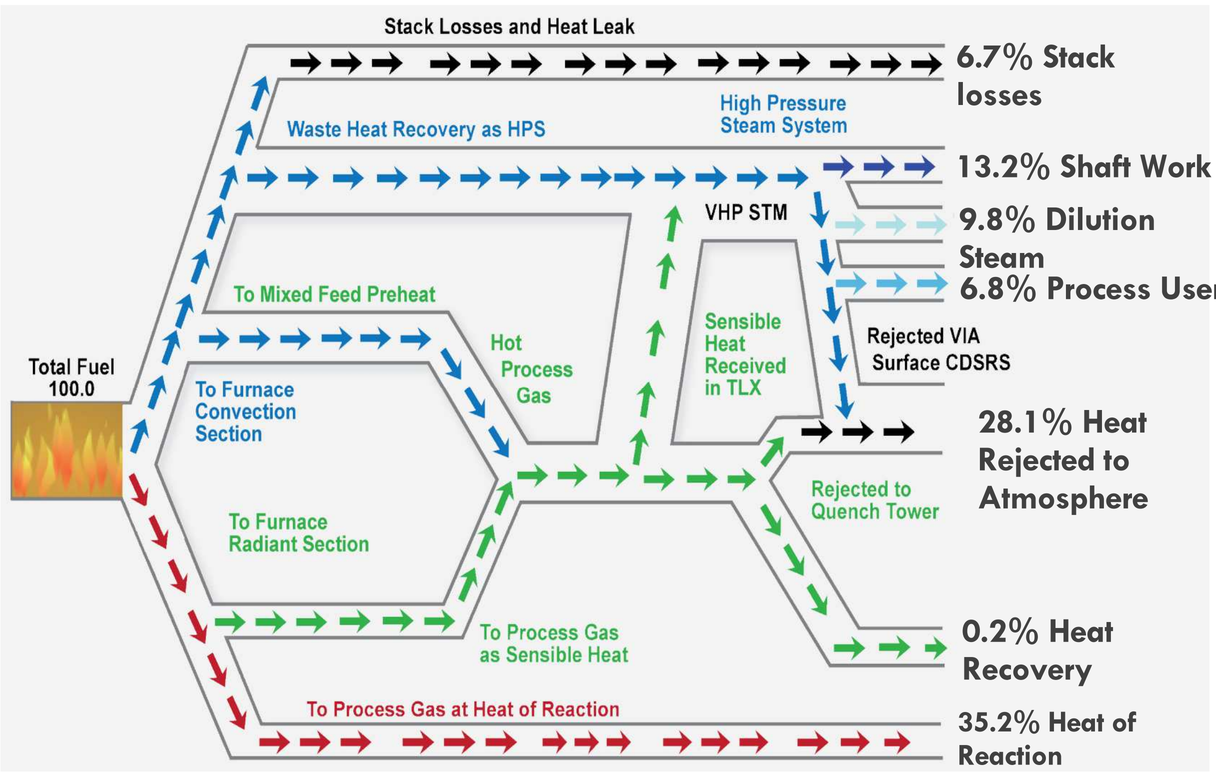


Source: EPA.gov/IPCC (2014)

~0.8% of global CO2 emissions!!

WHERE DOES ENERGY GO?

TYPICAL ETHANE CRACKER



Distribution	Percentage
Heat of Reaction	35.2%
Losses:	
Heat & Stack Losses	6.7%
Heat Rejected to Atm	28.1%*
Process Users:	
Major Drive Shaft Work	13.2%
DSG	9.8%
Other Process Users	6.8%
Heat Recovery	0.2%
TOTAL	**100%**

*Includes compressor surface condensers and QW coolers.

REDUCE CARBON EMISSIONS FROM STEAM CRACKING: SCOREKLEAN[SM]

KBR

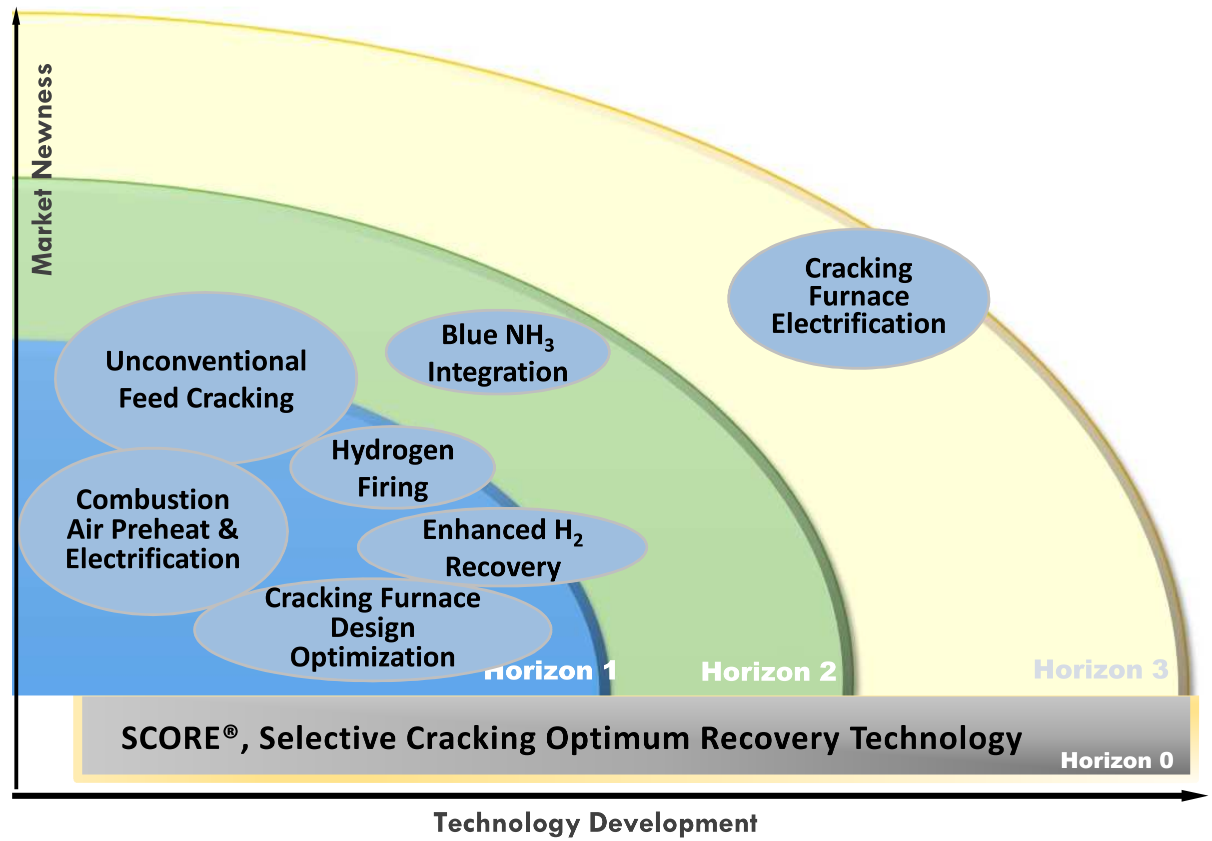
ENERGY Community of Practice

TIChE

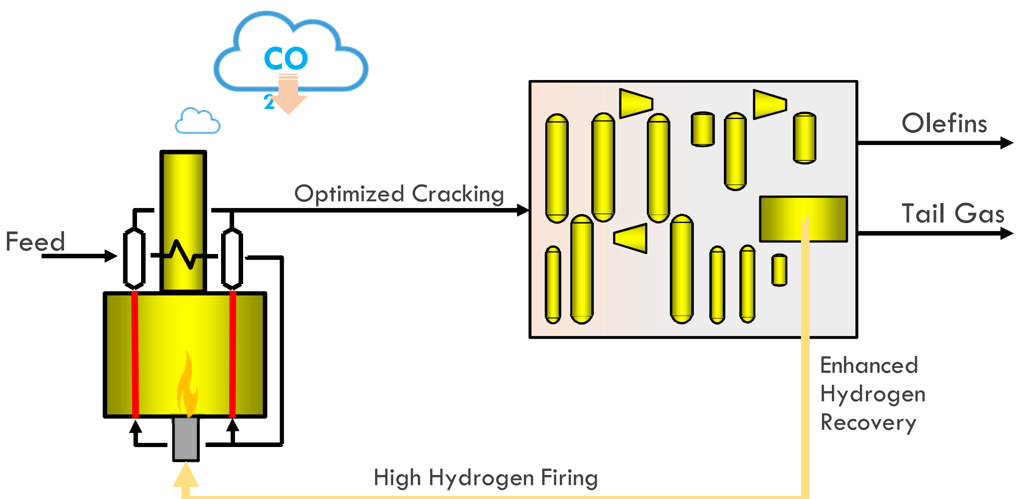
SCOREKLEAN℠ OVERVIEW

SCOREKlean℠ is a suite of decarbonization technologies for steam crackers that address direct, indirect, and other indirect emissions in the olefin value chain

Scope 1	Scope 2	Scope 3
Low CO2 designs utilizing Optimized Process Performance, Air Preheat, and Selective Electrification		Cracking Unconventional Recycled and Bio-Sourced Feedstocks
Hydrogen Firing		
Net Zero Integration with Blue Hydrogen or Carbon Capture		
Furnace Electrification		



HYDROGEN FIRING



Hydrogen firing is the most accessible way to decarbonize olefins production, by reducing carbon in the flue gas from pyrolysis furnaces

- 100% hydrogen combustion can be accommodated in SCORE® Furnace proprietary burners
- Existing connections existing in floor fired burners can be used to convert to 100% hydrogen firing
- Stable 100% hydrogen firing has been proven in our test facilities over a range of operating conditions
- Fuel flexibility is retained should hydrogen not be available
- Our ethane crackers have operated for over 15 years with fuel gas hydrogen content over 84 mol%

Enhanced hydrogen recovery designs maximize the recovery of hydrogen from the recovery section for firing in pyrolysis furnaces

JUBAIL UNITED PETROCHEMICAL COMPANY (JUPC)

Feedstock

- Ethane

Capacity

- 1000 KTA (Original, 2004); 1350 KTA (Expansion, 2006)

Reliability

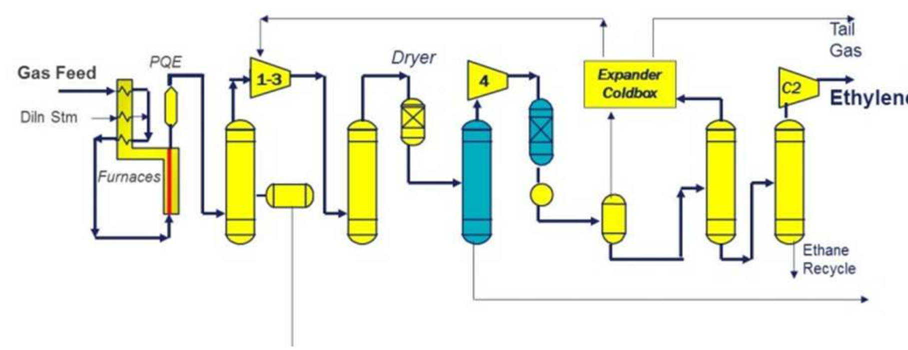
- Highest among all SABIC plants and Affiliates
- Back-to-back records of **798** days and **865** days continuous production
- Also completed **997** days prior to scheduled turnaround earlier this year

Operability

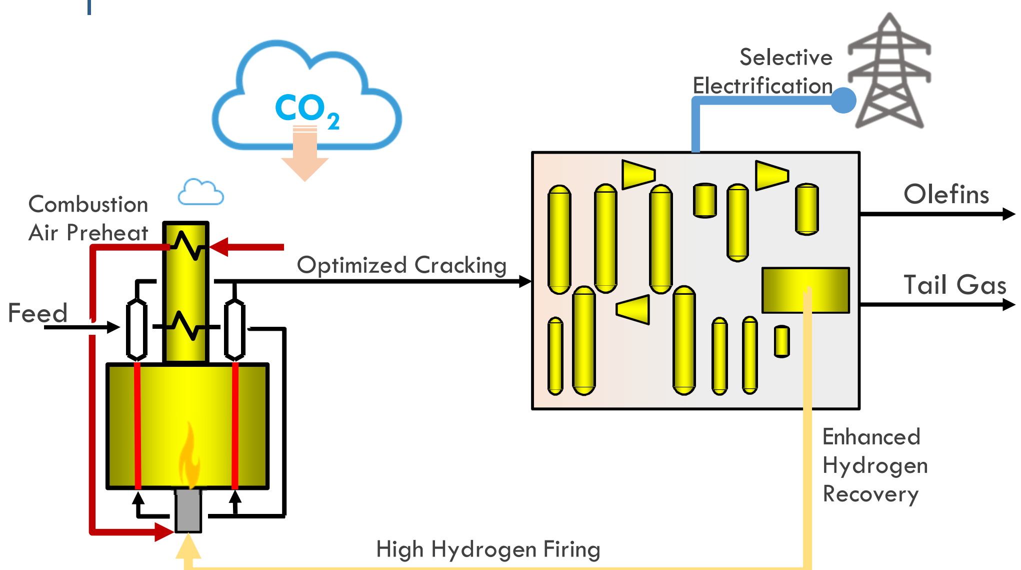
- 26 days from MC to on-spec product
- 18 hours from first hydrocarbon feed to on-spec product

Hydrogen Firing Capability:

- Operation with 84 mol% H_2 Fuel Gas
- Burner tested up to 90 mol% at burner vendor



LOW CO_2 CRACKER DESIGN

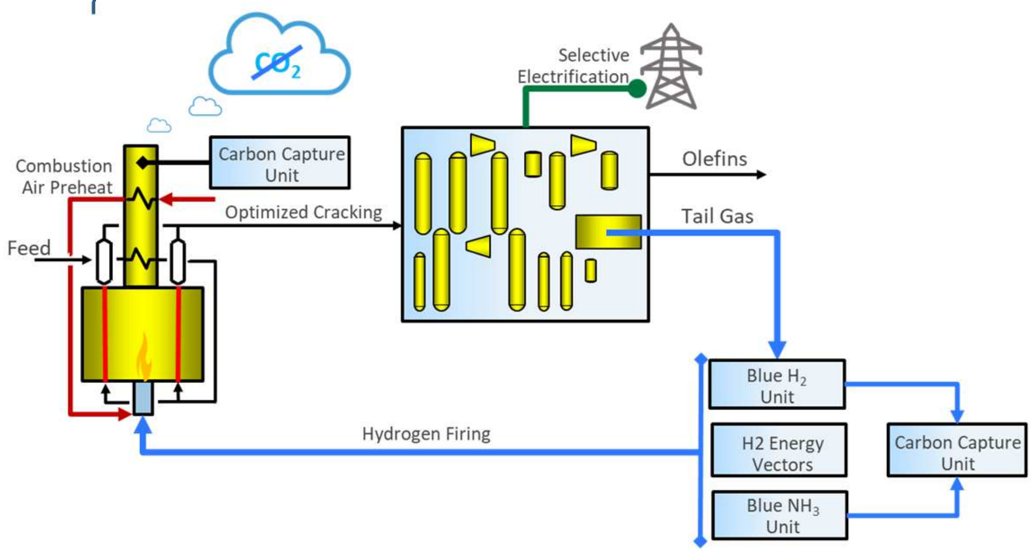


KBR SCOREKlean[SM] provides low CO_2 cracker design, emission reductions without requiring carbon capture or an external source of hydrogen by decarbonizing flue gas, reducing overall heat duty, and moving heat from the steam system into the process.

- High severity and pressure cracking using SCORE® technology reduces furnace firing rate and recovery section power requirements
- Combustion air preheat and selective recovery section electrification moves heat from the steam system into the cracking process, reducing fuel consumption
- Hydrogen firing combined with enhanced hydrogen recovery decarbonizes furnace flue gas
- Aspects of Low CO2 Cracker Designs are suitable for Greenfield and Revamp application

Standalone low CO2 ethane cracker designs can reduce direct emissions by 70%

NET ZERO CRACKER DESIGNS

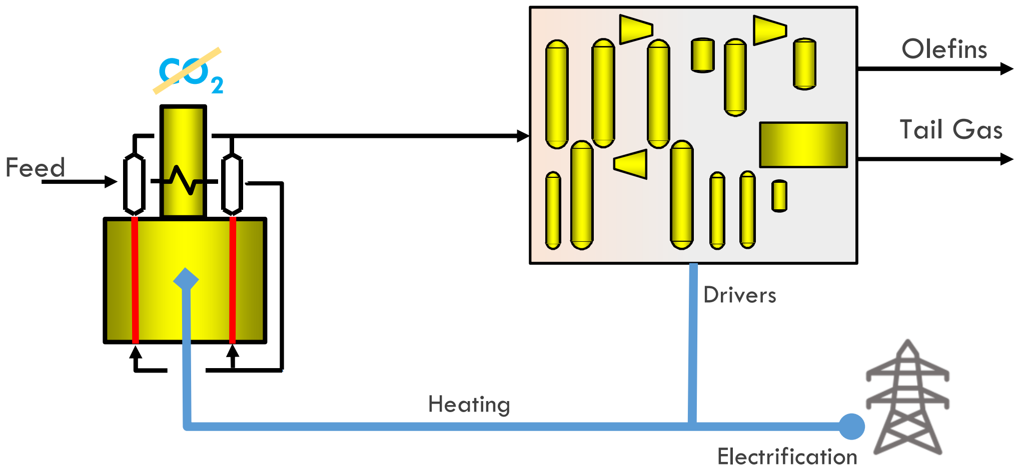


Net Zero steam cracker designs eliminate carbon emissions. This can be done through either blue hydrogen supply, blue ammonia facility, or utilization of KBR's post combustion carbon capture technology.

- Tail gas utilization designs use methane in tail gas to produce a decarbonized energy carrier such as blue hydrogen, or convert the methane into other chemical feedstocks, such as blue ammonia
- Hydrogen import or an energy vector may be used to supplement hydrogen from enhanced hydrogen recovery in the cracking process, without carbon capture
- Combustion air preheat and selective recovery section electrification moves heat from the steam system into the cracking process, reducing fuel consumption
- Alternatively, post-combustion carbon capture facility size is reduced by our Low CO2 cracker designs

KBR Net Zero cracker designs remove direct carbon emissions from steam crackers

CRACKING FURNACE ELECTRIFICATION



Steam cracking furnace electrification concepts are being developed, completely removing the flue stacks and direct emissions from pyrolysis furnaces.

- Options are being developed to electrify cracking furnaces, based upon indirect electrification and direct electrification
- Our electrification design concepts include configurations of electrical heat input, associated electrical systems and controls, and configurations of the furnace radiant and convection sections

Designing and operating an electrically powered Steam Cracking process is not new to KBR

- In 1991 KBR developed an electrified cracking furnace pilot plant
- A miniature version of an early version of our cracking furnace designs

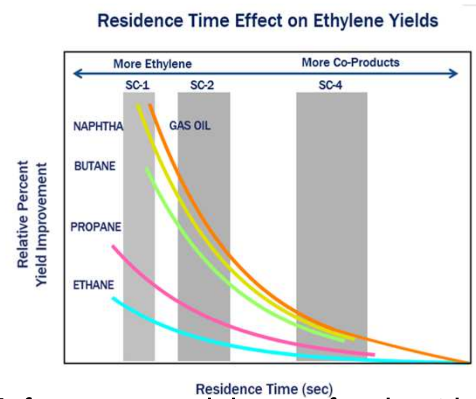
KEY ENABLERS FOR NET ZERO

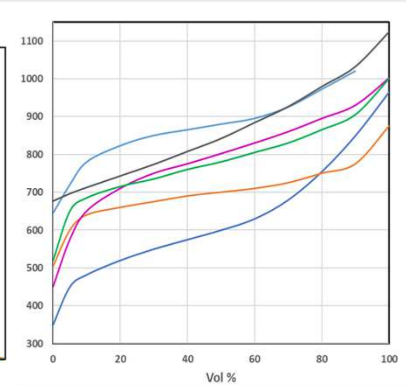
Technology	Revamp	New Build
Hydrogen Firing	YES	YES
Enhanced Hydrogen Recovery	YES	YES
Cracking Design Point Optimization	YES (More effective for Gas Cracking)	YES (More effective for Gas Cracking)
Combustion Air Preheat & Selective Process Electrification	CHALLENGING (Furnace Structure Adjustment)	YES
Unconventional Feed Cracking	YES	YES
Hydrogen Addition	YES (Fuel Gas Infrastructure Check)	YES
Cracking Furnace Electrification	CHALLENGING (New Tech. & Electrical Infrastructure)	MAYBE (New Tech. & Electrical Infrastructure)
Carbon Capture Integration	MAYBE (Plot Space & Carbon Sink)	MAYBE (Plot Space & Carbon Sink)
Blue Hydrogen Integration	MAYBE (Plot Space & Carbon Sink)	MAYBE (Plot Space & Carbon Sink)

UNCONVENTIONAL FEEDSTOCK CRACKING

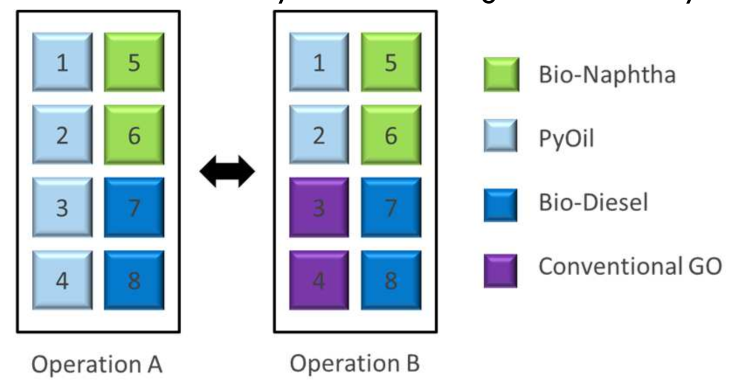
KBR has leveraged its experience in unconventional feed cracking for bio-sourced and recycled feedstock.

- Studies have looked at the constraints in cracking heavier feedstocks (such as pyoil) in different areas of existing steam cracking furnaces:
  - Mixed feed coil, PQE, SQE, Radiant Coil, and PFO treating facilities
  - The impact of impurities within unconventional feedstocks
- Unconventional deployment strategies have been evaluated for existing furnaces:
  - Dilution versus designated coil passes versus upgrading
  - KBR has various upgrading options unconventional feedstocks
- New Furnace installations can be specified to crack heavier feedstocks
- Hybrid-cracking (splitting the firebox into 8 passes) could have great benefits in cracking different types of feeds when:
  - Amounts of unconventional feed from the single source is not enough for full furnace capacity and Co-cracking is not favored due to yield loss
  - Various feed cracking at optimum cracking conditions for the best yields is required
  - Feed supplies are not fully secured, and it needs to replace the feed with different type of feeds





SC-1 furnaces crack heavy feeds with high relative ethylene yield



Hybrid cracking different feedstocks in single firebox

DECARBONIZATION TOOLKIT FOR EXISTING CRACKERS

Bio-Feed Cracking

Cracker Design Point Optimization
- Higher COP
- Higher Severity

Enhanced H2 Recovery & Firing
- Recovery System
- Burner Modifications

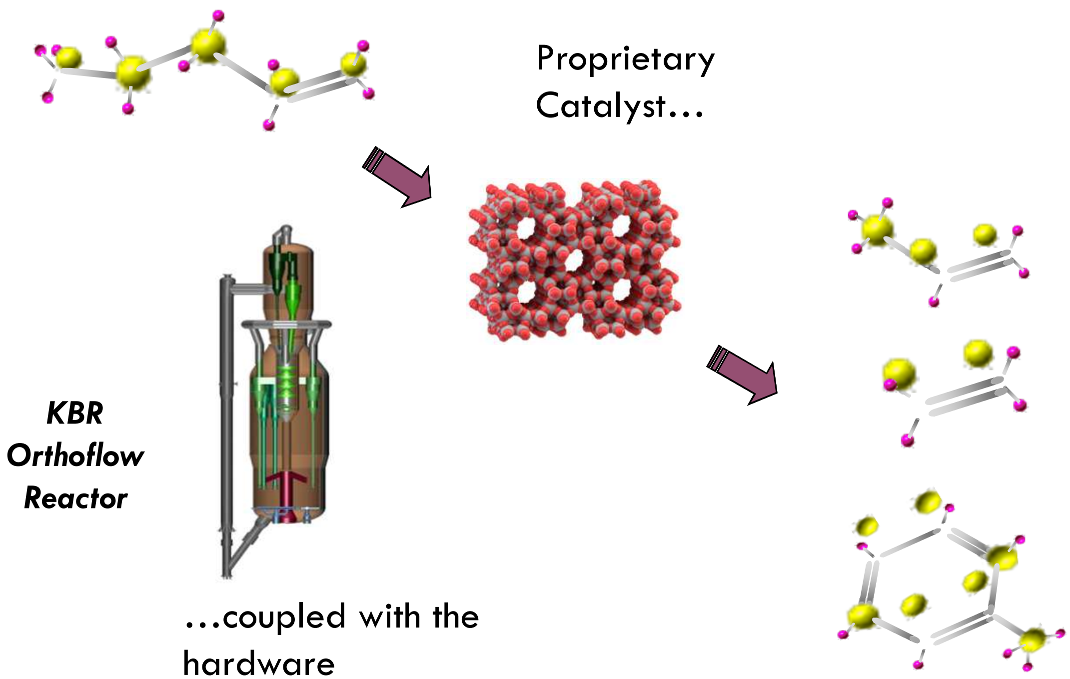
Transfer Heat From Steam to Process
- Air Preheat
- SQE Feed/Effluent

Selective Process Electrification
- Electric Motor Drives

OTHER OLEFINS TECHNOLOGY DECARBONIZATION

KBR CONFIDENTIAL

K-COT® : KBR CATALYTIC OLEFINS TECHNOLOGY



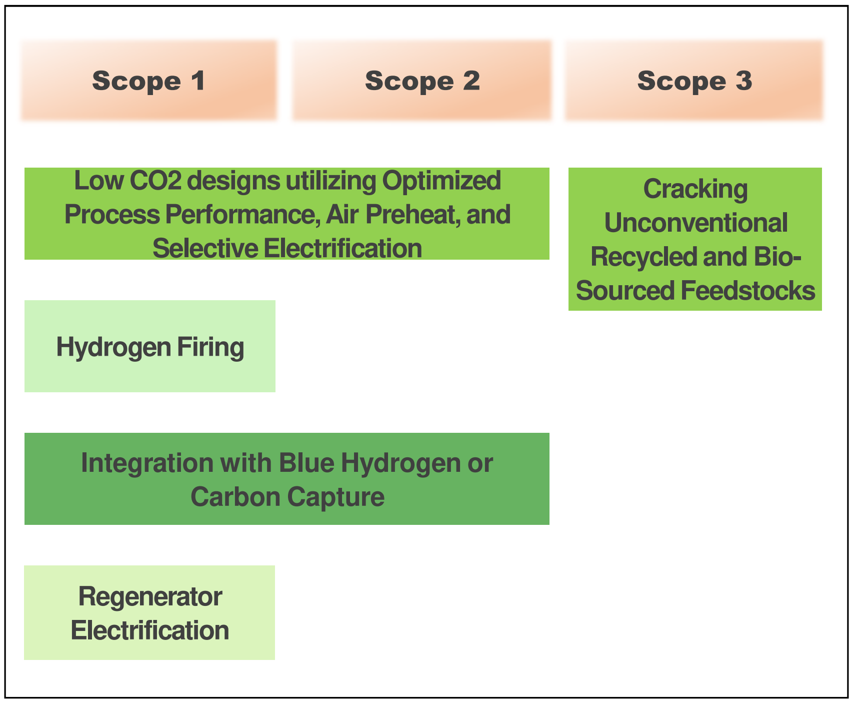
KBR Proprietary Modified ZSM-5 catalyst

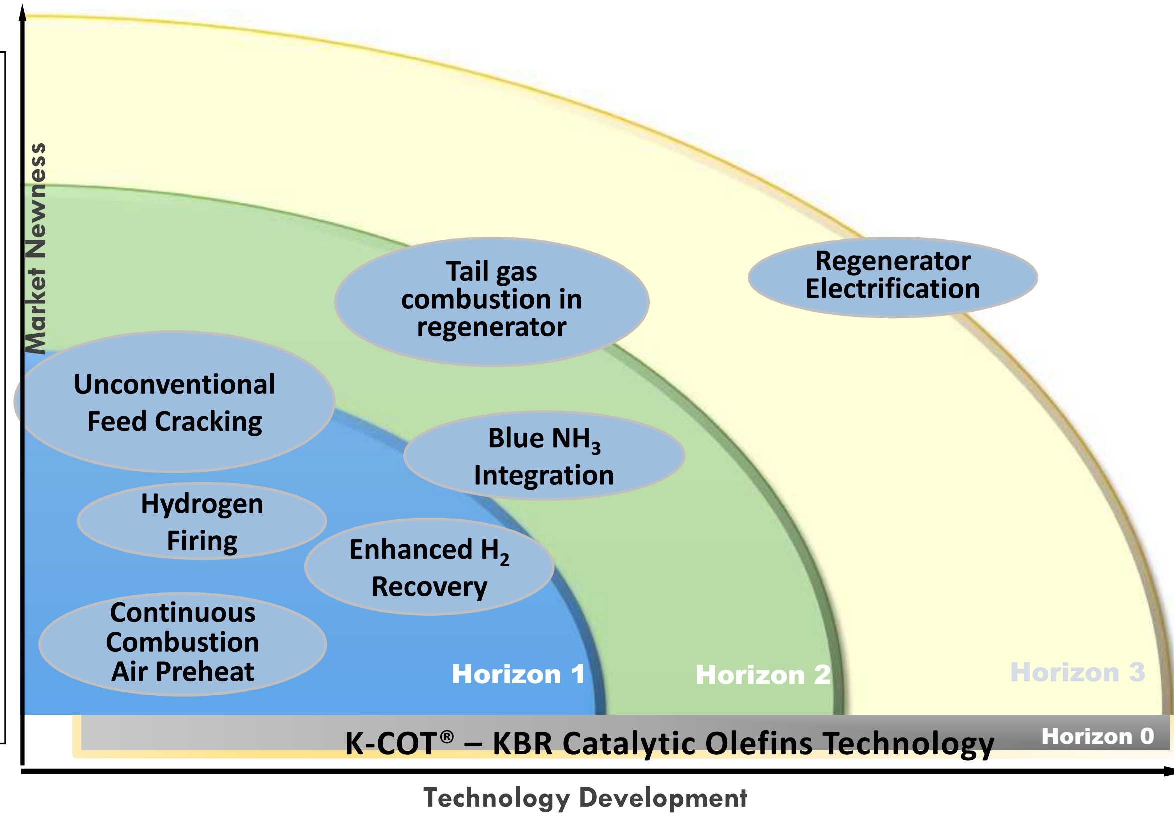
KBR's well proven Orthoflow fast fluidized reactor with 70 years experience

KBR's over 100 olefins plant design experience

K-COT® DECARBONIZATION

KBR is developing a suite of decarbonization technologies for K-COT that address direct, indirect, and other indirect emissions in the olefin value chain





REDUCING CO_2 EMISSIONS FOR K-COT®

CARBON CAPTURE

- End of Pipe Solution
- CAPEX Intensive
- CO_2 Disposition Issues

But, easier to implement on K-COT® – only one flue gas point source

- Modern Grassroots Facilities Highly Energy Efficient
- Incremental Improvements
- Minor Impact on CO2 Emissions

Flow scheme provided in the studies already include Latest design improvements

ENERGY EFFICIENCY

ELECTRIFICATION

E-Drives for all Compressors

- Significant Steam Export/Major impact on Utility System(s)

Catalyst E-Heating

- Use power instead of fuel for catalyst heating – significant power requirement

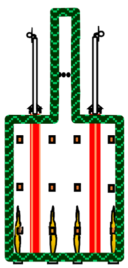
Motor drivers could be applied; KBR has commercial experience with this in K-COT®

- Hydrogen Sourcing Challenges
- Fuel Gas Disposition
- CFD Modelling Planned

KBR intends "proof of concept" via CFD modeling – but it requires a source of "blue hydrogen"

HYDROGEN AS FUEL

KBR OLEFINS TECHNOLOGIES



SCORE®

- Steam Cracking Process
- Furnace Flexibility: Ethane to Gas Oil
- Highest Yield in Industry
- Lower CAPEX
- Lowest CO_2 Footprint

K-COT®

- Catalytic Olefins Process
- C4 – C10 Olefinic, Paraffinic or Mixed Feeds
- Higher Propylene-to-Ethylene Production
- Energy Transition Technology: Upgrading Low Value Gasoline Streams

MTO Recovery

- Optimized Recovery Section Design
- Low CAPEX and OPEX

K-PRO®

- Propane to Propylene (PDH)
- FCC Based: Easier to Operate and More Reliable
- Environmentally Friendly Catalyst
- Lower CAPEX and OPEX

K-SEET℠

- Ethanol to Ethylene Technology
- Newest addition to Olefins Portfolio
- Production of ‘bio-ethylene’