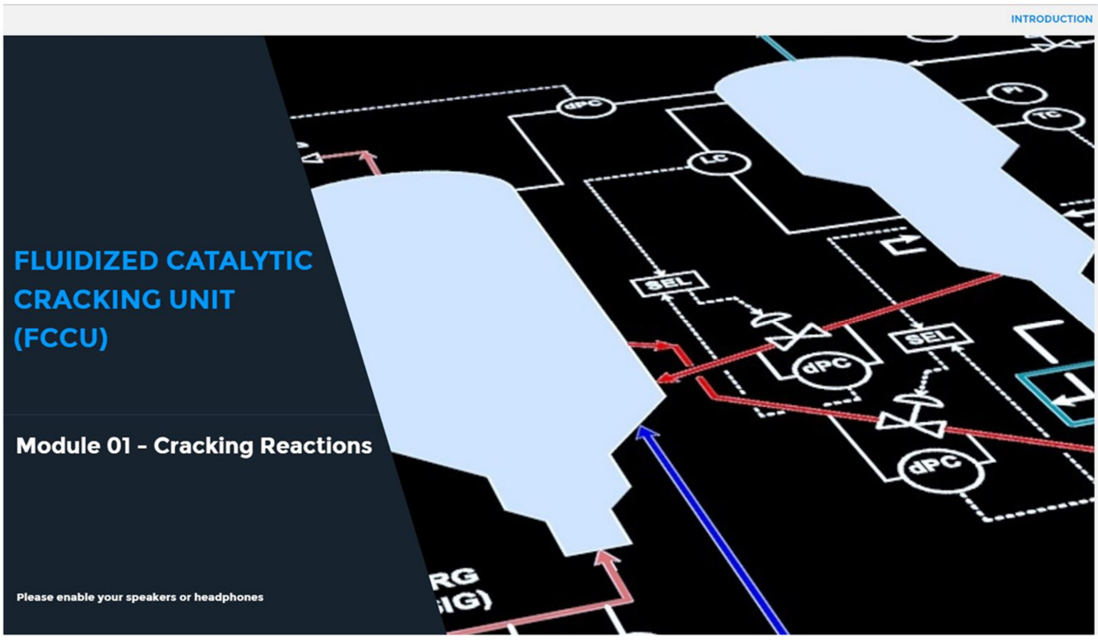
BU MEASUREMENT & ANALYTICS

Refinery Process Units

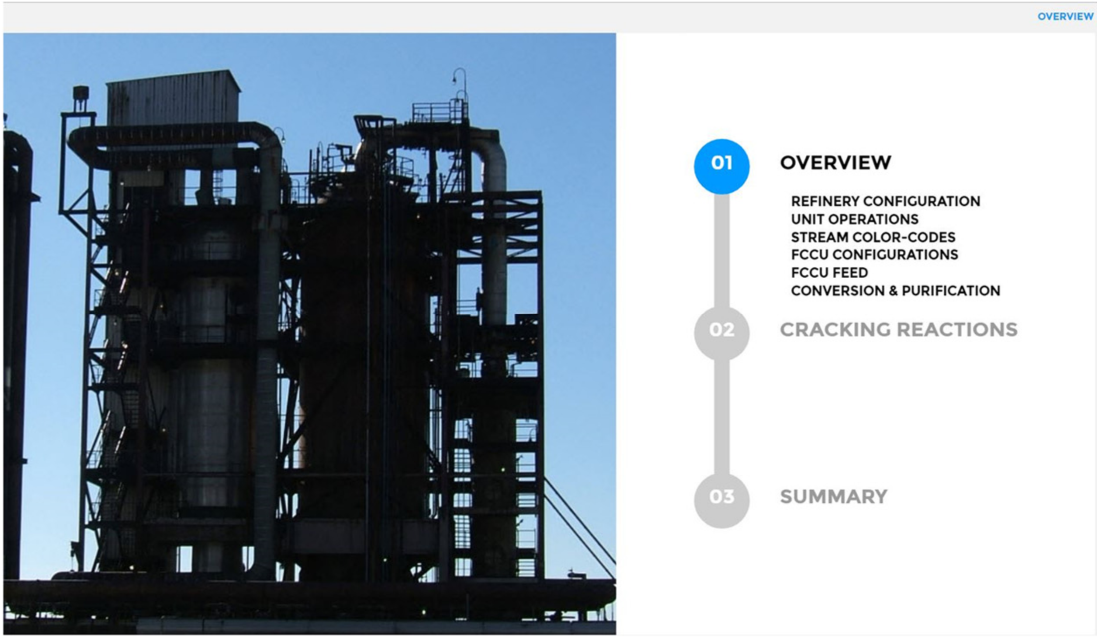
Fluidized Catalytic Cracking Unit (FCCU) – Module 1: Cracking Reactions



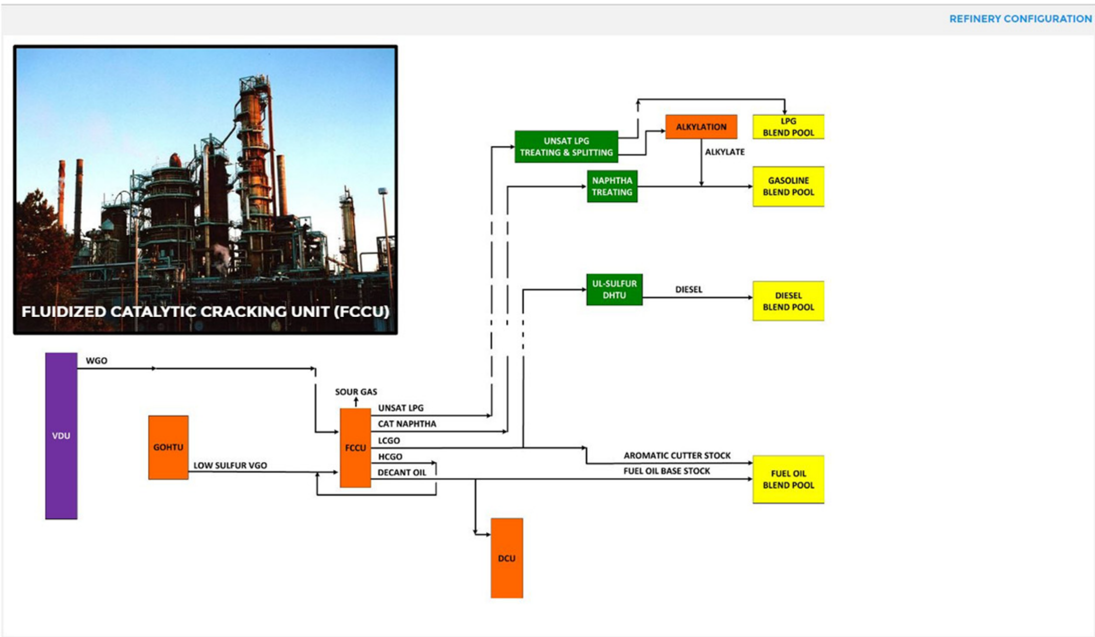
Welcome to the Fluidized Catalytic Cracking Unit Module 01, which covers cracking reactions.

Upon completion of this module, you should have a basic understanding of:

- The concept of operating the reactor and regenerator in heat balance
- The affect of feed characteristics on cracking reactions
- The parameters that assist and hinder cracking reactions
- The major constraints on cracking reactions



Let’s start with a brief Overview of the FCCU.



Here's our now-familiar Refinery Configuration Diagram that shows the Primary Separation Units in purple, Secondary Conversion Units in orange, Tertiary Treating Units in green and Export Products in yellow.

The FCCU is a Secondary Conversion Unit.

Low sulfur Vacuum Gas Oil (VGO) from the GOHTU and a small quantity of Wet Gas Oil (WGO) from the VDU pass as feed to the FCCU.

The FCCU catalytically cracks the low-value, low-demand heavy feed at high temperature to form the following products:

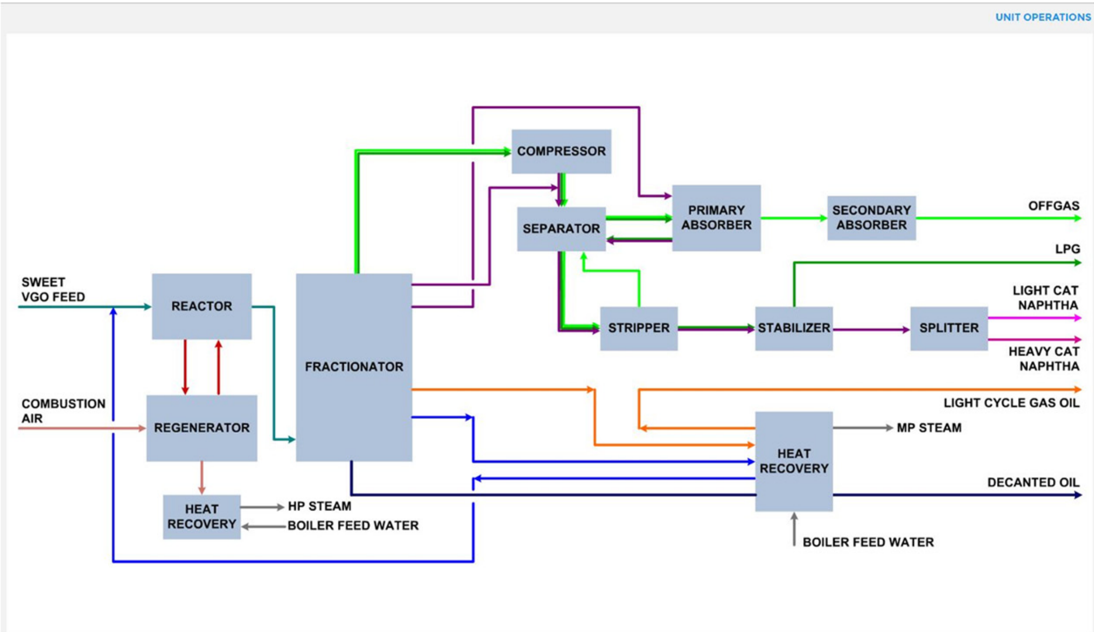
> Sour Gas that's treated and passed to the refinery fuel gas system
>
> Unsaturated LPG and Catalytic Naphtha that are chemically treated and blended into finished LPG and gasoline
>
> Light Cycle Gas Oil (LCGO) that is hydrotreated and blended

into finished diesel or used as an aromatic fuel oil viscosity cutter

Heavy Cycle Gas Oil (HCGO) that is recycled internally and processed to extinction, and

Decanted Oil that either passes to the fuel oil blend pool or as feed to the Delayed Coking Unit

The FCCU makes a significant contribution to refining economics by reducing the size of the fuel oil pool and enhancing gasoline production.

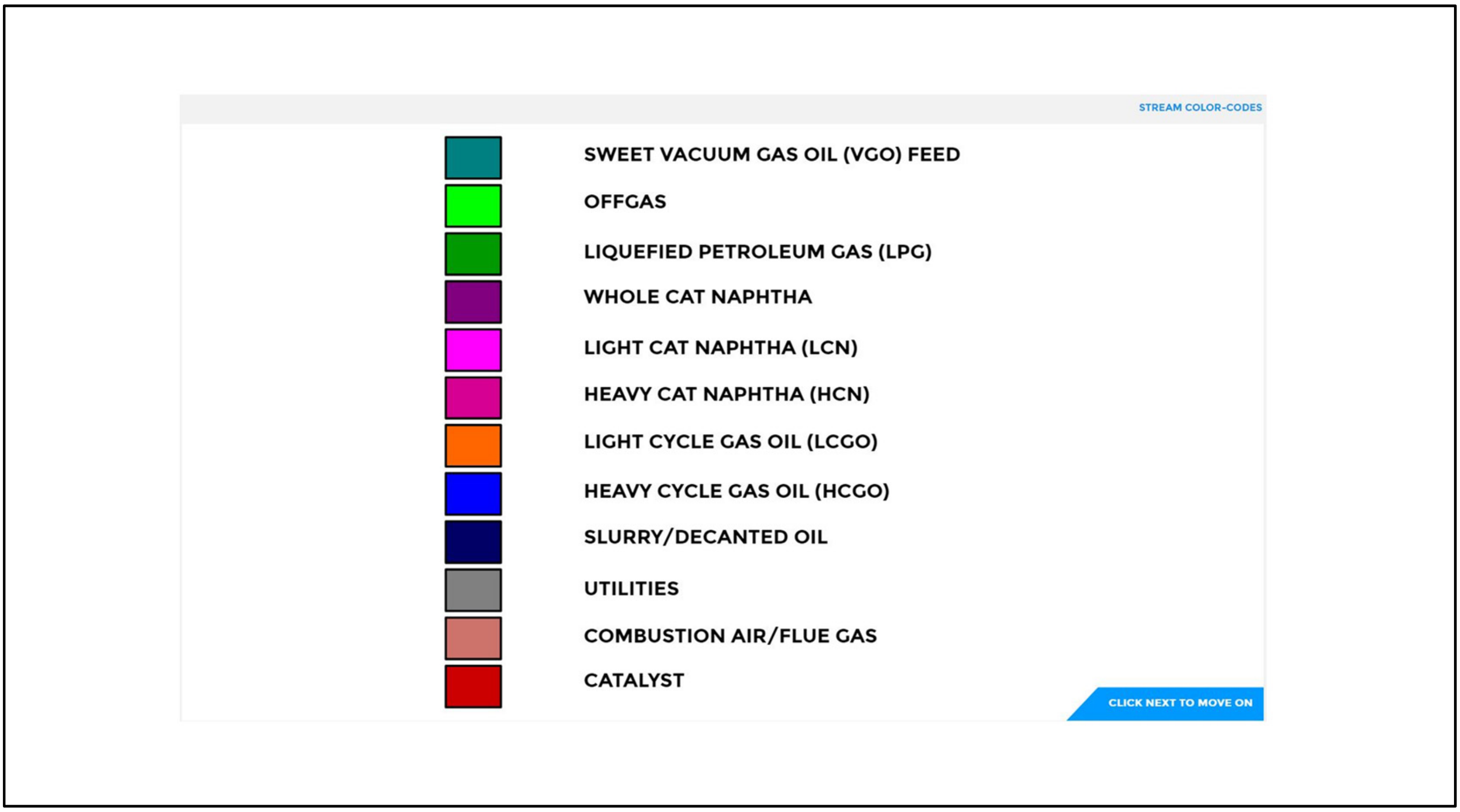


The FCCU has several unit operations that are split into modules as shown in this diagram:

Module 2 will cover the feed system and the reactor

Module 3 will cover the regenerator and flue gas heat recovery system

Module 4 will cover the main fractionator and gas plant



Here are the stream color-codes that we're going to be using.

You'll find these are consistent with those we have used in earlier programs.

Please take a moment to familiarize yourself with the color-codes and then click next when you are ready to move on.

The FCC process has been around for a long time.

The first commercial plant went into service in 1942.

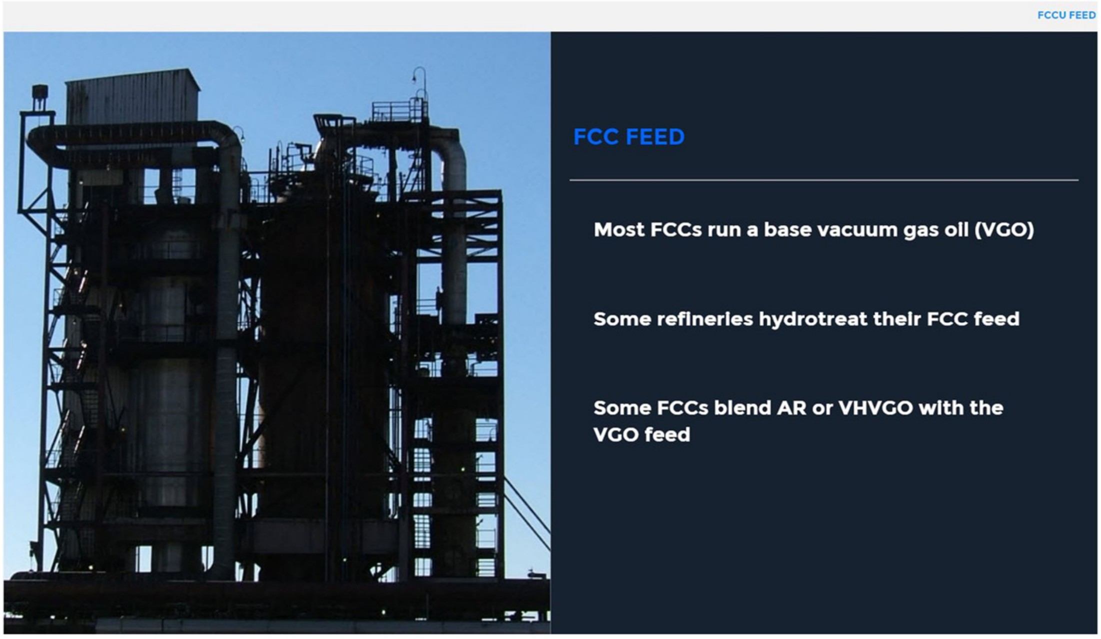
Since then, FCC designs have steadily evolved - each improving on its predecessor.

Today, there are two principal configurations. The first is the side-by-side configuration (where reaction and regeneration take place in separate vessels located alongside one another).

The second is the stacked configuration (where reaction and regeneration take place in a single vessel; reaction on top, regeneration below).

In addition to the construction of new plants, many older FCC reactors and regenerators have been revamped to retrofit improved design features.

All configurations are commercially proven and not unsurprisingly all licensors claim to have the best design and boast a variety of economic advantages over their competitors.

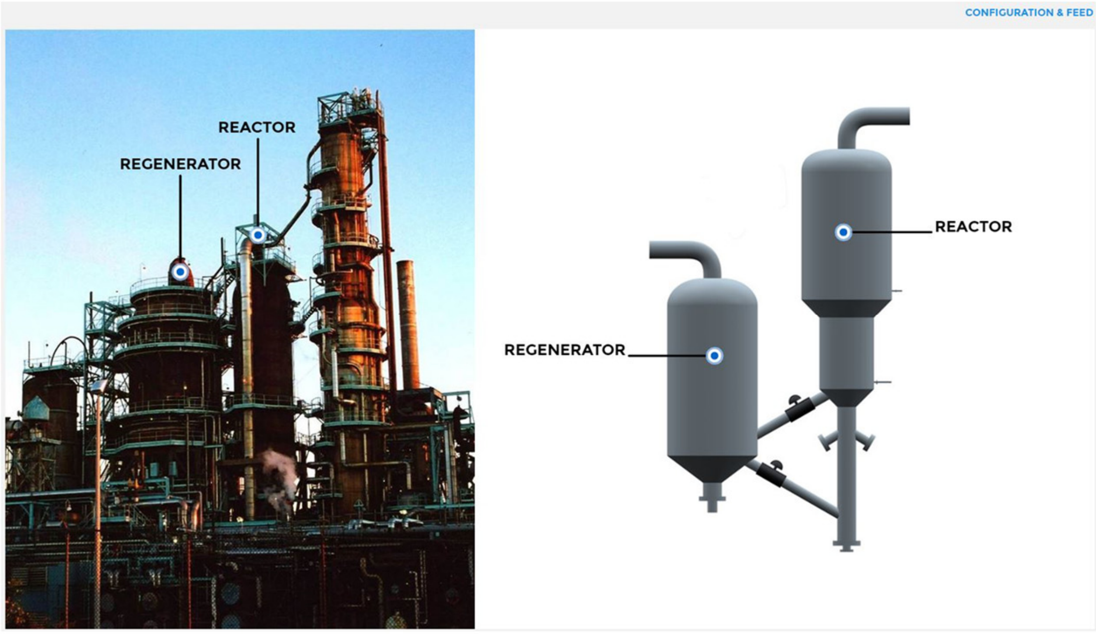


In addition to reactor-regenerator configuration, FCCs also have variations in the type of feed that is run.

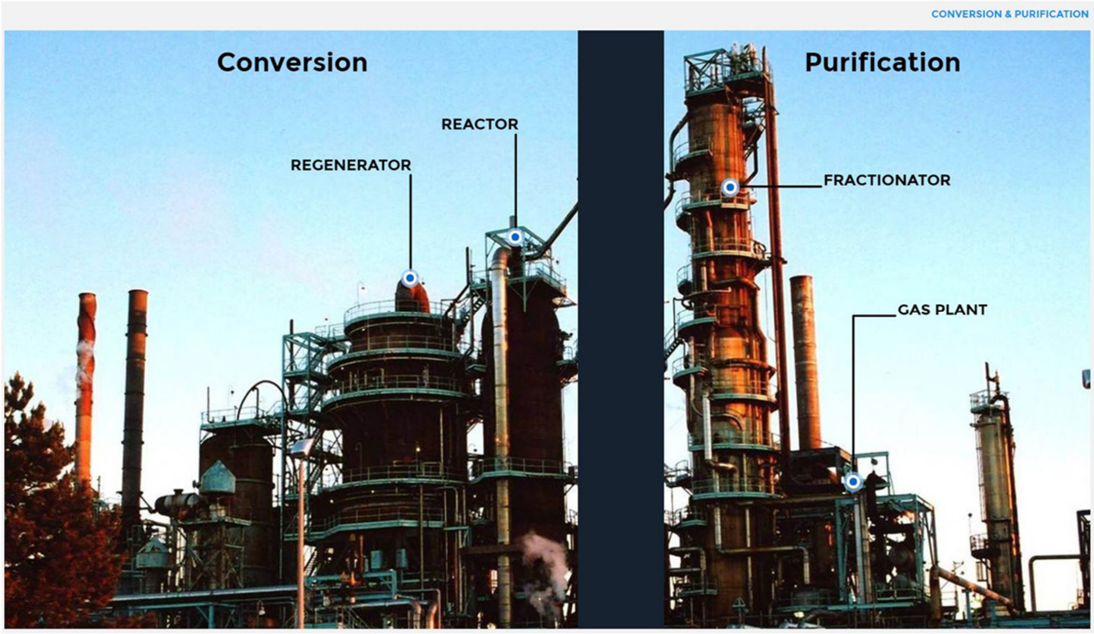
Most FCCs run a base vacuum gas oil (VGO) feedstock - some refineries hydrotreat their FCC feed to remove sulfur and nitrogen, others don’t.

FCC feed hydrotreating generates many processing benefits in terms of increased conversion of heavy stocks to lighter ones and less downstream treating required to remove potential pollutants from the products.

Some FCCs blend atmospheric residue or very heavy vacuum gas oil in with the VGO feed - this requires special design features to accommodate the increased metals and carbon content of the heavier feed.



In this e-learning program, we're going to limit our discussions to a side-by-side reactor-regenerator configuration with a sweet (i.e. hydrotreated) VGO feed with no inclusion of heavier stock.

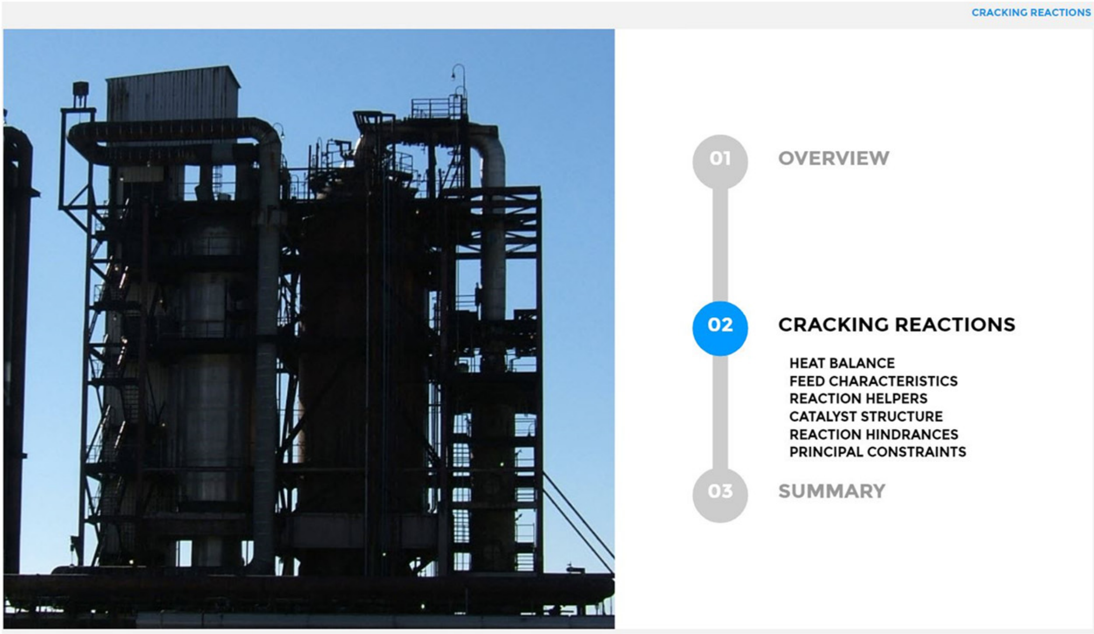


The FCC is sub-divided into two basic systems:

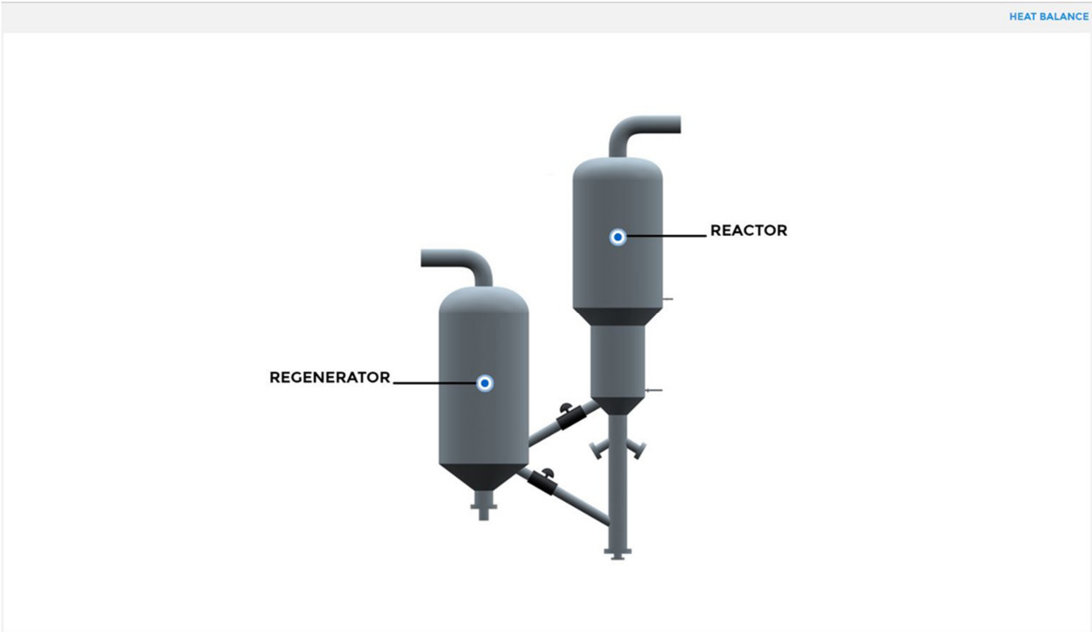
Conversion, which features the reactor and regenerator, and

Purification, which includes the main fractionator and the gas plant

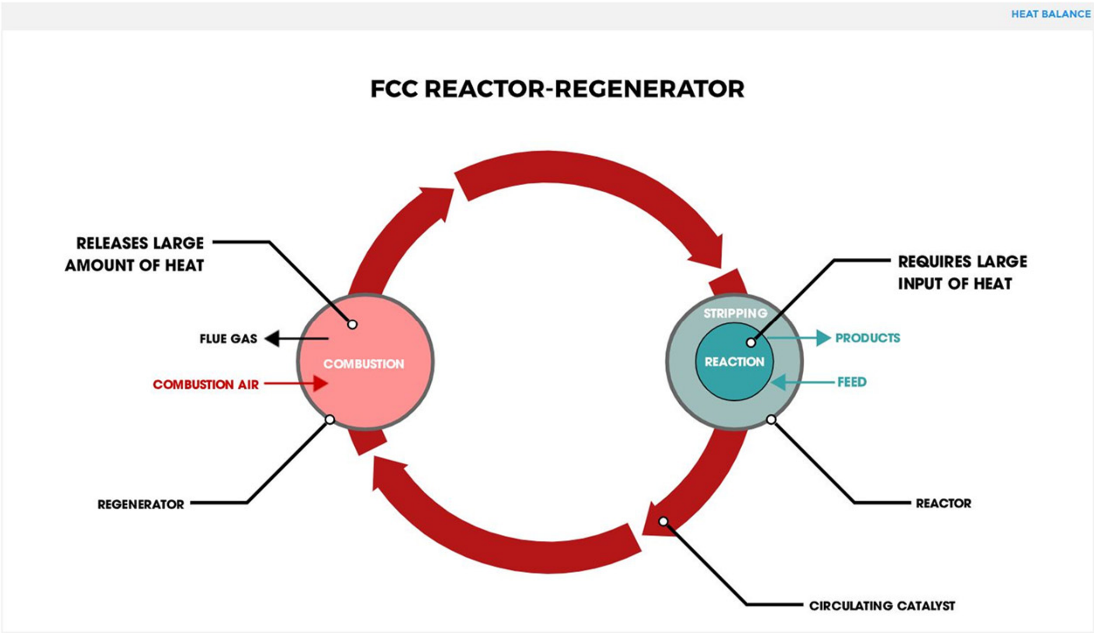
From plant-to-plant, naming conventions for the gas plant do vary, you may also hear it referred to as the unsaturated gas plant or the gas concentration unit.



Ok, now you've had a brief overview, we'll make a start on cracking reactions.



We'll begin by discussing the thermal effects that take place in the reactor and regenerator and introduce you to the concept of heat balance.



This simple diagram represents the reactor-regenerator system. Hot catalyst circulates continuously between the reactor (on the right) and the regenerator (on the left).

We'll look at the reactor first. Liquid hydrocarbon feed is steam atomized into droplets that enter the reactor and vaporize as they contact the hot circulating catalyst.

In the presence of heat and catalyst, a portion of the feed cracks to form lighter boiling hydrocarbon products.

As the cracking reactions proceed, carbon (or coke) and heavy hydrocarbons deposit on the surface of the catalyst.

In the reactor, the hydrocarbons are steam stripped from the surface of the catalyst and mixed with the lighter hydrocarbon products and uncracked feed, exiting as a vapor stream from the top.

Next, the regenerator.

The catalyst exits the bottom of the reactor and passes to the regenerator where coke is removed from the catalyst surface by burning it in air to form carbon dioxide, which is removed as a flue gas stream along with uncombusted oxygen, carbon monoxide, nitrogen, water vapor and traces of sulfur and nitrogen oxides.

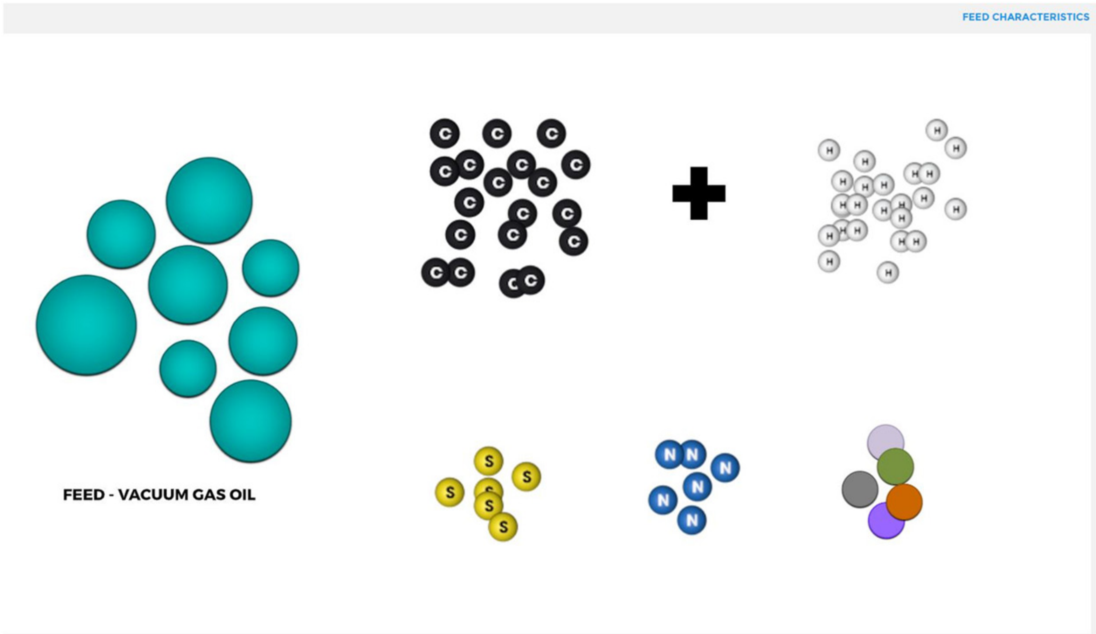
Most regenerators burn to completion with minimal carbon monoxide present in the flue gas.

The cracking reactions that take place in the reactor are endothermic - that means heat is required in order to initiate and sustain the cracking reactions - the source of that heat is the circulating catalyst.

By contrast, the combustion reactions that take place in the regenerator are exothermic - that is, they give off heat.

Some of that heat is retained by the circulating catalyst and passed back to the reactor. The remainder exits the regenerator in the flue gas stream, which passes to a heat recovery system and is used to generate steam.

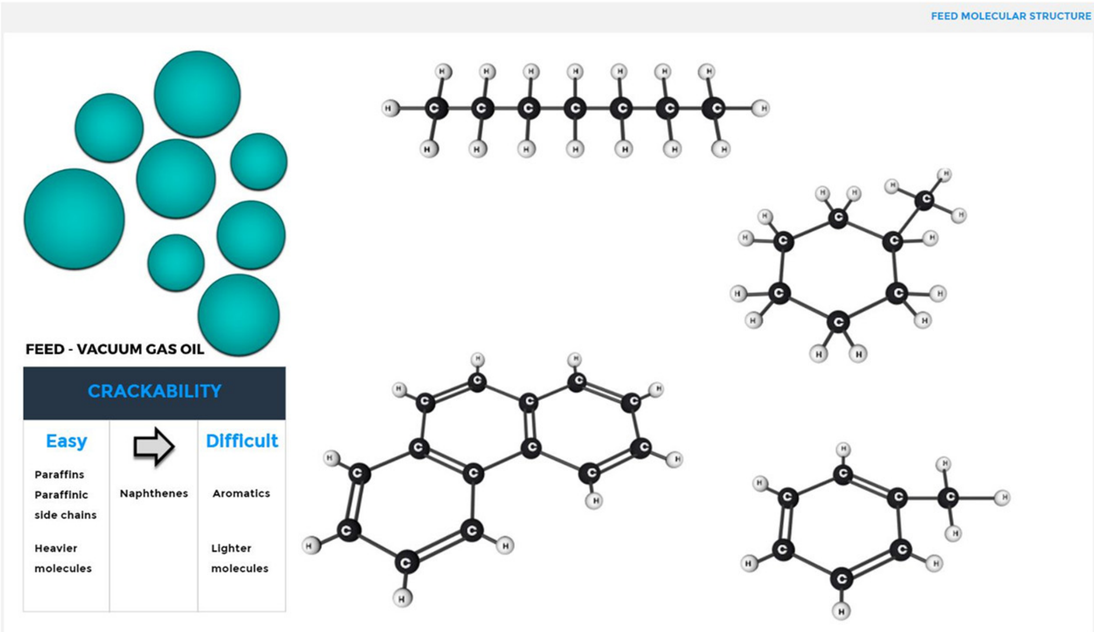
Due to the dependent relationship between the endothermic and exothermic reactions, the reactor and regenerator are said to run in heat balance.



Next, we'll take a look at the effect of feed characteristics on the cracking reactions.

VGO is primarily a mix of carbon and hydrogen atoms, arranged in various hydrocarbon structures, containing embedded atoms of sulfur and nitrogen and metals.

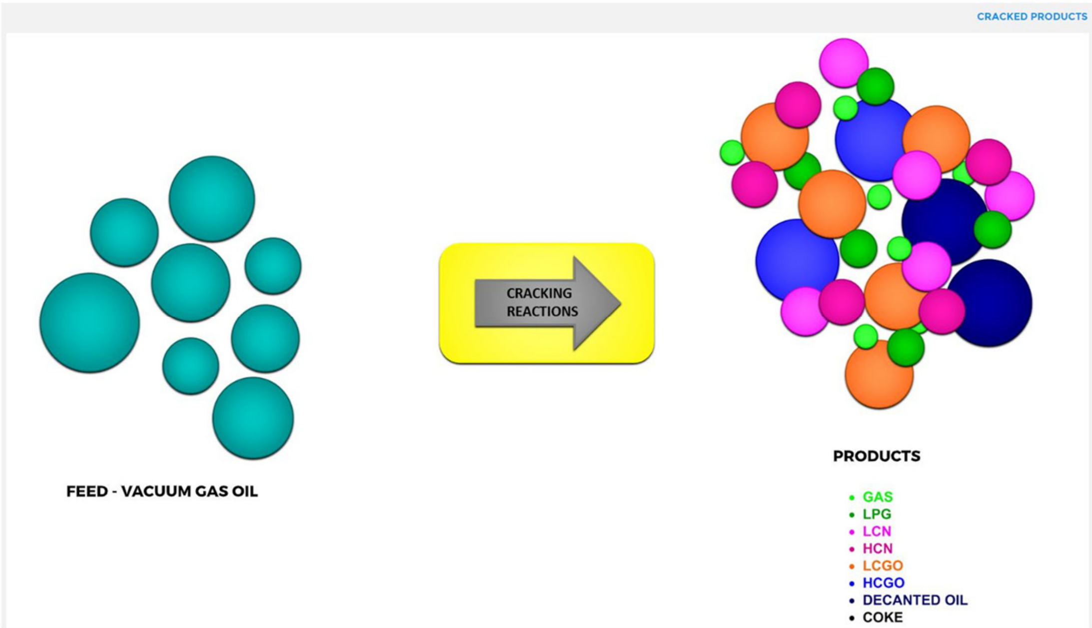
Hydrotreating VGO feed removes the bulk of the sulfur, nitrogen and metals, so sweet VGO contains only trace quantities of these contaminants.



The VGO hydrocarbons are arranged in paraffinic, naphthenic, aromatic and poly nuclear aromatic structures.

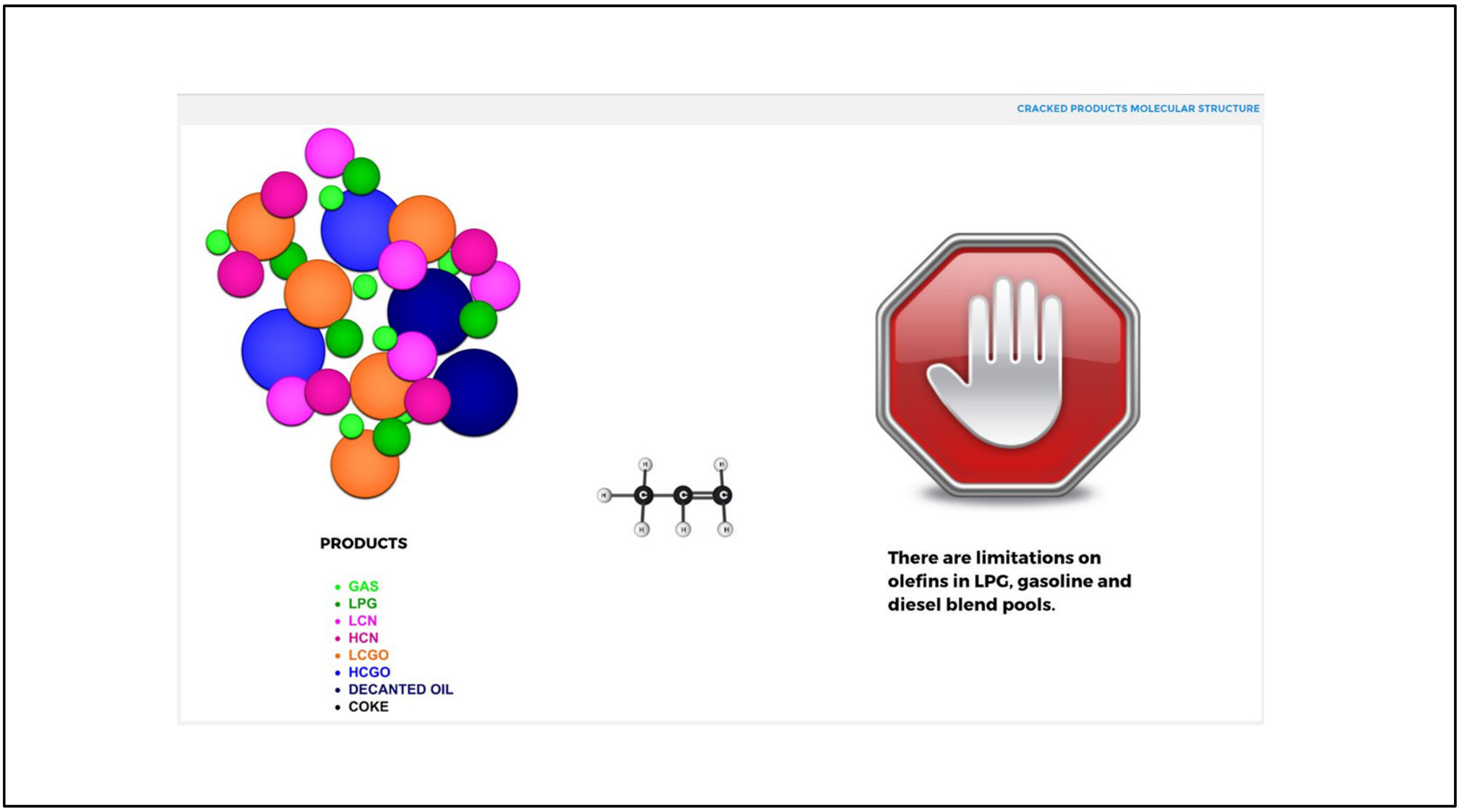
In terms of crackability, paraffins and paraffinic side chains are the easiest to crack, then naphthenes and lastly aromatics.

Also, molecules with a high boiling range (i.e. heavier molecules) tend to crack much more easily than lighter ones.



The reactions generate a number of cracked products such as gas, LPG, LCN, HCN and LCGO together with residues of HCGO and Decanted Oil, which are essentially the uncracked portion of the feed.

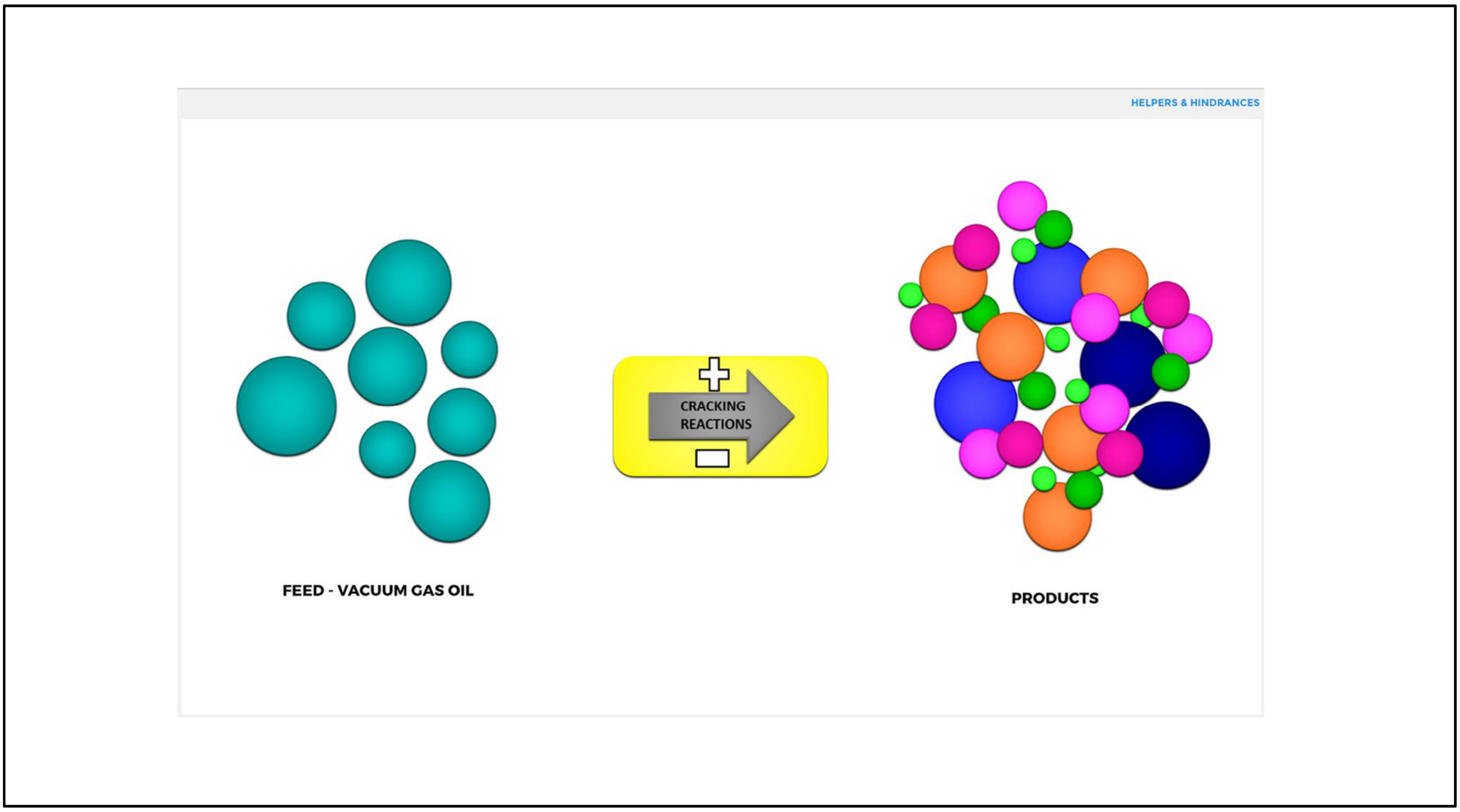
The cracking reactions also produce coke, which is deposited on the surface of the catalyst.



The molecular structures of the cracked products are much the same as those of the feed, paraffinic, naphthenic and aromatic with an additional structure - the olefin.

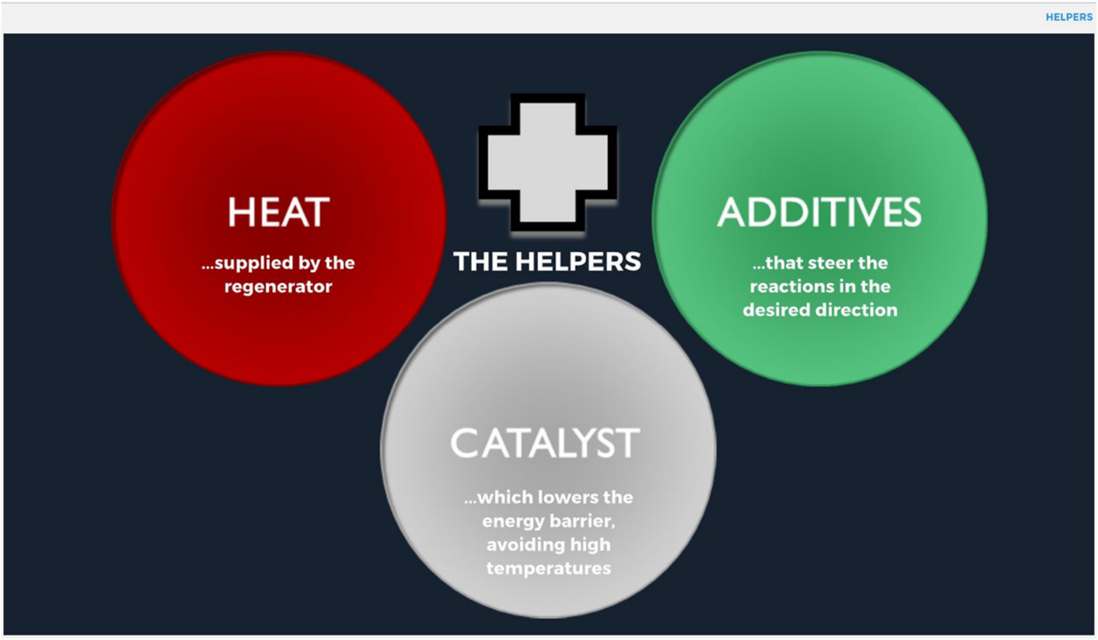
Olefins are chemically unstable hydrocarbons that are produced when heavy hydrocarbons are cracked in a hydrogen deficient atmosphere, i.e. there is insufficient hydrogen present to fully saturate the carbon-to-carbon bonds in the hydrocarbon structure.

There are limitations on olefins in LPG, gasoline and diesel blend pools.



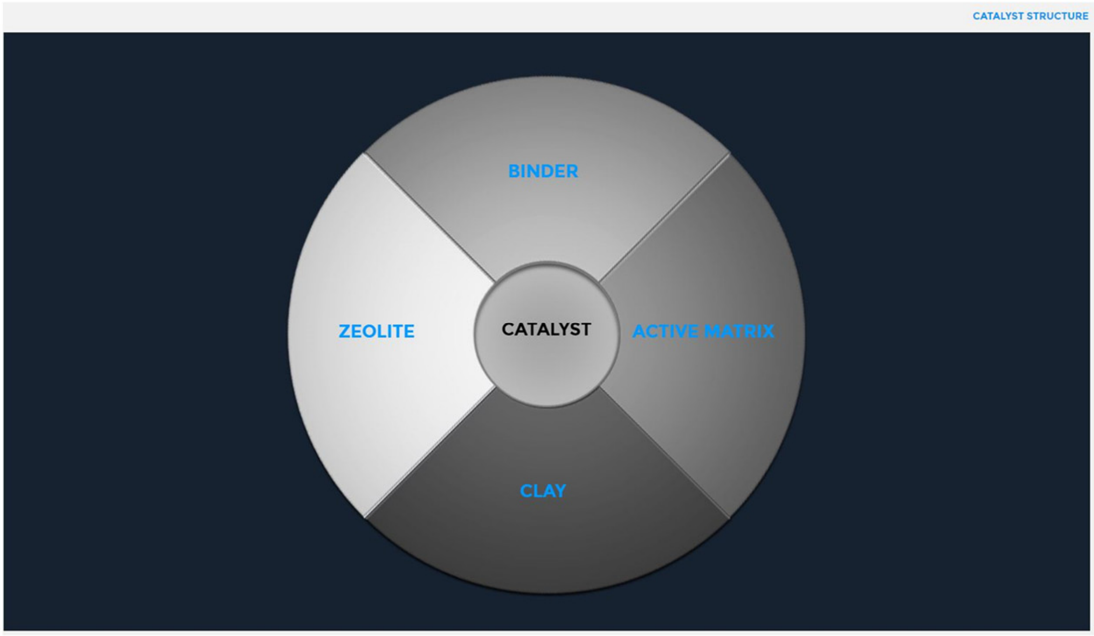
In FCCs, there are some parameters that help the cracking reactions and some that hinder them.

We'll take a brief look at these. First, the helpers.



The endothermic cracking reactions are helped by heat (supplied by the regenerator), catalyst (which lowers the energy barrier, avoiding high temperatures that lead to undesirable thermal cracking) and additives (that steer the reactions in the desired direction).

Some additives are injected into the feed, others are mixed with the catalyst.



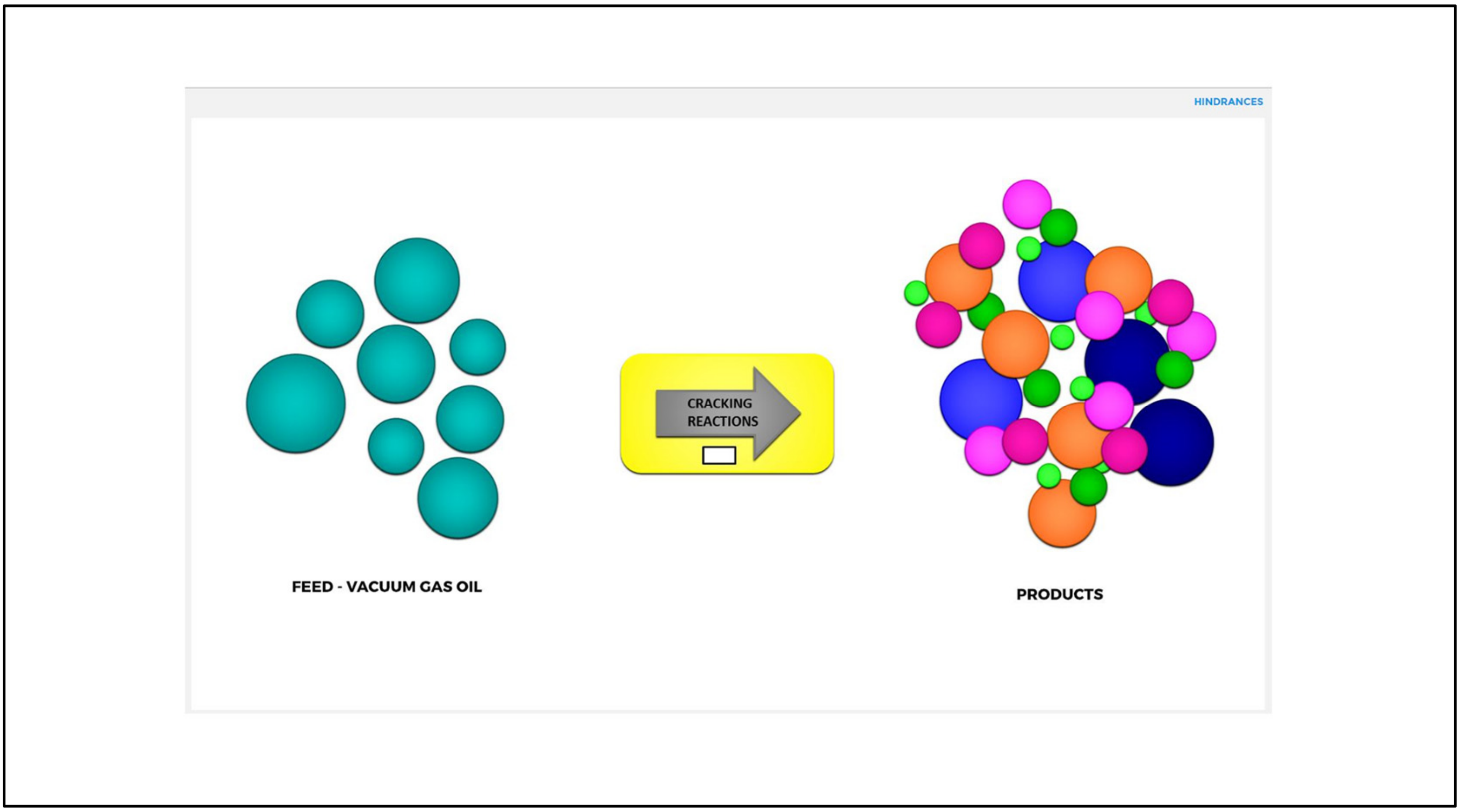
Let’s take a brief look at the structure of the catalyst, which has four components - active matrix, zeolite, clay and a binder:

The active matrix component cracks heavy gas oil molecules into lighter ones

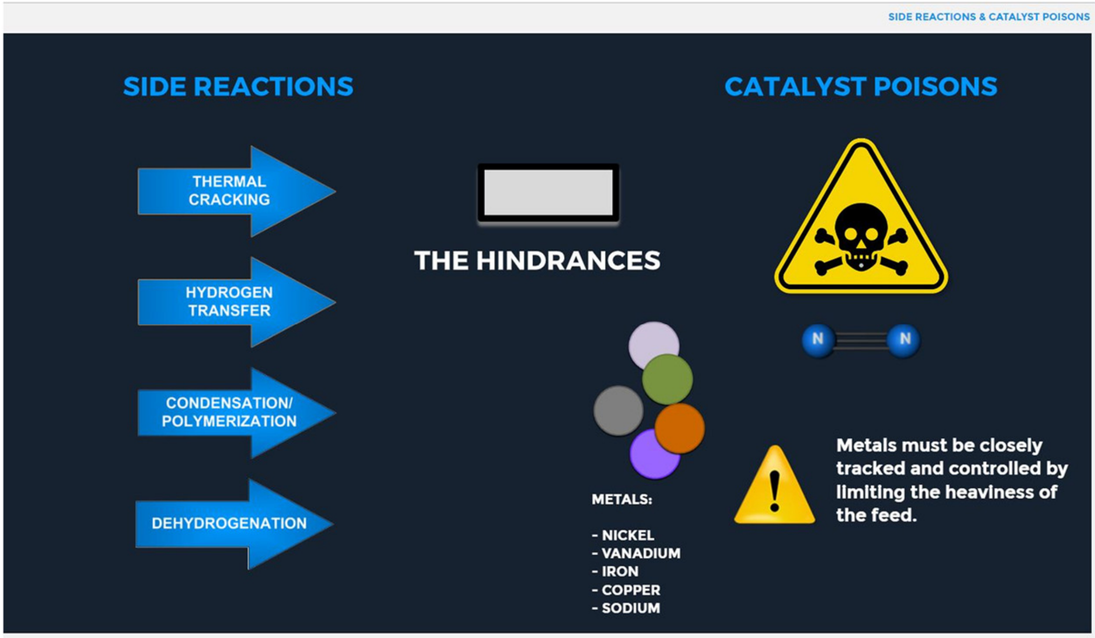
Zeolite cracks the light gas oils into C_3 and C_4 molecules

Clay brings important physical properties to the catalyst mix, such as density, physical strength and bulk

The binder acts as a glue that holds the zeolite, active matrix and clay components together - in doing so, providing physical strength and attrition resistance



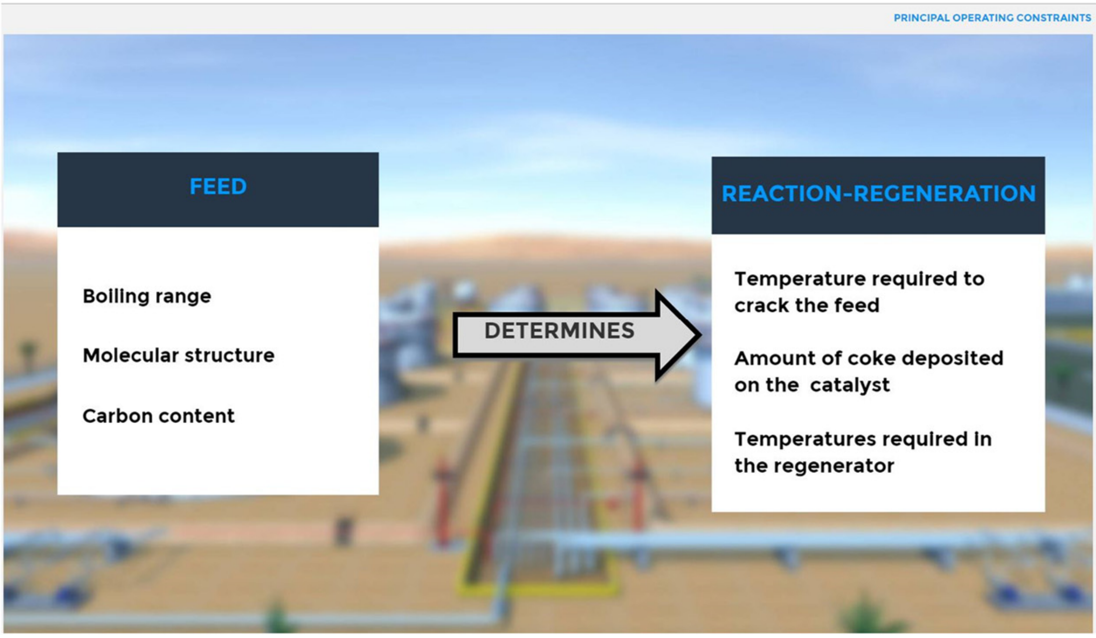
Next some things that hinder the cracking reactions.



Hindrances fall into two categories, side reactions and catalyst poisons:

Side reactions are controlled by a combination of careful attention to the formulation of the catalyst, close monitoring and control of reaction conditions and adjustment of additives

Our FCC runs a sweet feed so catalyst poisons are not too much of a concern but they would be if we were running sour feed – for sour feed, while there's not much that can be done about the nitrogen content, metals must be closely tracked and controlled by limiting the heaviness of the feed



We'll finish up this module by pointing out the principal constraints on FCC operation – there are quite a few and they're going to surface in the following modules in the sections on operating problems. For now, we'll just consider the main two.

The boiling range, molecular structure and carbon content of the feed determine the temperature required to crack it and the amount of coke deposited on the surface of the catalyst.

The latter determines the temperatures that are required in the regenerator to burn off the coke and these are constrained by mechanical design temperature limitations on the regenerator shell and internal components.

Catalyst under-performance can also be a major constraint.

FCC catalyst performance can be seriously reduced by the presence of poisons, high temperature deactivation, prolonged high temperature contact with steam and incorrect formulation.

The catalyst can also be broken into fines through attrition as it moves through the reactor and regenerator, with the fines ultimately being lost to the regenerator flue gas and lost to atmosphere.

Don't worry if you don't understand all of this at this juncture - we'll be explaining it in more detail in the following modules and by the end of the program you’ll have a much clearer understanding of catalytic cracking.

And this completes FCCU Module 01 in which we've covered cracking reactions.

To summarize:

- The FCC catalyst cracks heavy hydrocarbon molecules into lighter ones that can be blended into light and middle distillate products
- Heavy molecules with paraffinic structures are the easiest to crack while light molecules with aromatic structures are the hardest
- The reactor and regenerator run in heat balance with the combustion reactions in the regenerator providing the heat to initiate the cracking reactions in the reactor
- The cracking reactions are helped by heat, catalyst and additives and hindered by side reactions and catalyst poisons
- The principal constraints on cracking reactions are the heaviness and carbon content of the feed and parameters that cause under-performance of the catalyst

As you complete this module, you should now have a basic understanding of:

- The concept of operating the reactor and regenerator in heat balance
- The affect of feed characteristics on cracking reactions
- The parameters that assist and hinder cracking reactions
- The major constraints on catalytic cracking

Your task now is to take the FCCU Module 01 Quiz to ensure you have fully understood the material.

If you find the questions challenging, you should consider repeating this module before moving on to the next one.

Good luck!

You can now close this module.