Capturing Maximum Value with Tight Oil Feeds in the FCC

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What is Tight Oil?

- The term Tight Oil (sometimes referred to as shale oil) is used to describe oil produced from low permeability (e.g. tight) shale, sandstone and carbonate rock formations
- The USA is legally prohibited from exporting crude to other nations → hence all domestic tight oil production will be consumed in the USA
  - US refiners achieve a cost advantage compared to other global refineries
  - The abundant natural gas from tight oil production also gives manufacturing an advantage
  - Pricing for fields like Bakken low due to transportation infrastructure bottlenecks

Source EIA (US Energy Information Administration)

Shale Plays

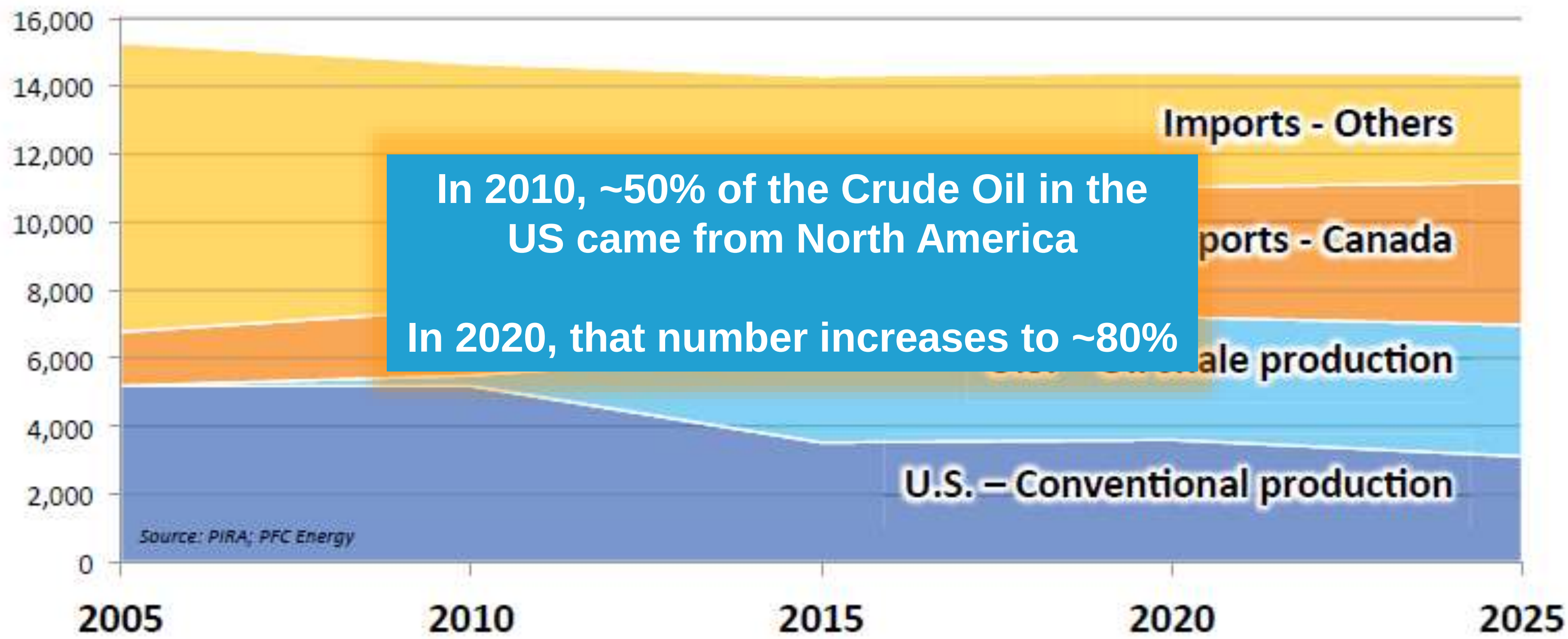
Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Technically Recoverable Shale Oil Resources (Billion Barrels)	
1. Russia	75
2. US	48
3. China	32
4. Argentina	27
5. Libya	26
6. Australia	18
7. Venezuela	13
8. Mexico	13
9. Pakistan	9
10. Canada	9
11. Others	65
TOTAL	**335**

Tight Oil is Here to Stay

In 2010, ~50% of the Crude Oil in the US came from North America

In 2020, that number increases to ~80%



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Tight Oil Quality

- High naphtha and middle distillate cuts
- Almost no vacuum resid
- Lower: boiling point, S, N, CCR, Ni, V,
- Can have higher Na, Ca, K and Fe
- Quality varies even from the same field!

Tight Oil Quality Variability from One Field
Source Baker Hughes

Properties	TX Shale	Bakken Core	WTI	Maya Blend	Peace River	Cold Lake	Wabasca
Crude API	47.9	41.9	41	31.2	32.3	20.3	19.2
Crude Sulfur	0.09	0.14	0.32	1.84	2	3.9	3.99
Offgas	3.0%	2.7%	1.8%	1.5%	2.3%	1.6%	0.6%
Naphtha	27.4%	27.8%	24.6%	18.0%	15.7%	16.3%	12.9%
Mid Distillate	40.2%	36.9%	38.6%	33.7%	33.6%	18.1%	26.2%
VGO	26.0%	27.2%	26.7%	28.2%	28.6%	28.4%	32.6%
Vac Resid	3.4%	5.5%	8.3%	18.6%	19.9%	35.6%	27.8%

Source KBC

Tight Oil Quality Impacts on the Refinery

- Crude processing capacity severely affected by the increased volume of the lighter oil cuts
- The naphtha cut of tight oil is more paraffinic → lower octane
  - Consider using ZSM-5 to increase FCC gasoline octane within gas plant constraints
  - Reformulate FCC catalyst to a lower REO
  - Alkylation will be an important part of the refinery configuration
  - Refiners are maxing out the reformer capacity
- With low vacuum resid consider shutting down the resid units and feeding the resid directly to the FCC (helps with FCC heat balance)
- Crude compatibility needs to be considered when blending light/sweet crudes with heavy/sour crude due to asphaltene precipitation

FCC Tight Oil Feed Cut Quality

- VGO Cut
  - Very low Sulfur
  - Same or lower Nitrogen
  - Low metals
  - Low carbon producing feed
- Resid properties show similar behavior

VGO Properties		TX Shale	Bakken Core	WTI	Maya Blend	Peace River5	Cold Lake	Wabasca
API Gravity		31.9	24.5	26.3	21	24.4	14.9	13.4
Sulfur	wt%	0.18	0.27	0.46	2.05	2.29	3.56	4.31
Acidity	mg KOH/g	0.049	0.053	0.095	0.085	0.522	1.279	1.658
Nitrogen	wt%	0.01	0.11	0.13	0.18	0.13	0.12	0.16
Refractive Index	67°C	1.4588	1.4824	1.4759	1.498	1.4832	1.5257	1.5351
Nickel	ppm	0.09	0.47	0	0.64	0.07	1.8	3.79
Vanadium	ppm	0.08	0.14	0	4.48	0.28	5.18	5.1
Con Carbon	wt%	0.03	0.68	0.01	0.47	0.07	1.69	1.41

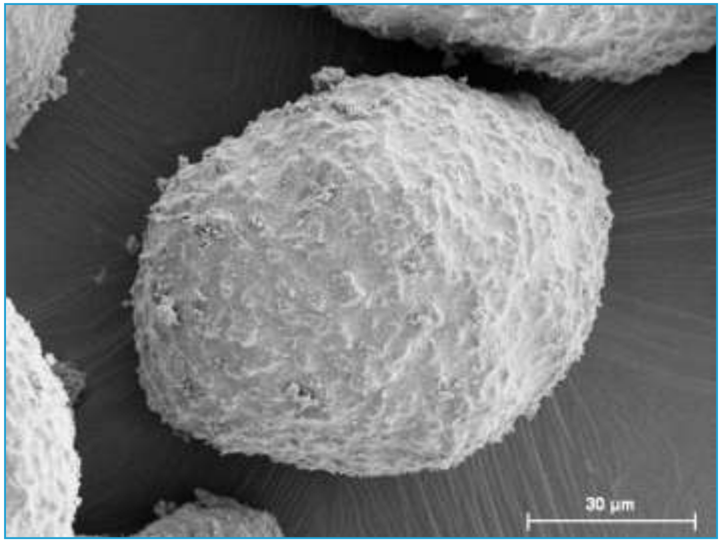
Source KBC

FCC Operation with Tight Oil

- If Feed Sulfur is reduced:
  - Help meet the Tier 3, 10 ppm Gasoline spec. Consider using Gasoline Sulfur Reduction additives such as BASF's LSA to meet spec without capital investment .
  - Lower SOx emissions from the stack. Consider cutting back if using a SOx additive.
- Lower NOx emissions from less Nitrogen in feed
- Higher LPG yields which may limit the gas plant
- Less hydrogen and coke from lower metals
- Tight Oil has lower coke making tendencies which may constrain the unit on **heat balance**
- Some chemical we are seeing include: Barium, Phosphorus, and Lead. However, the chemical levels are low and have no discernible effects on the FCC yields or catalyst selectivities.

Iron in Tight Oil

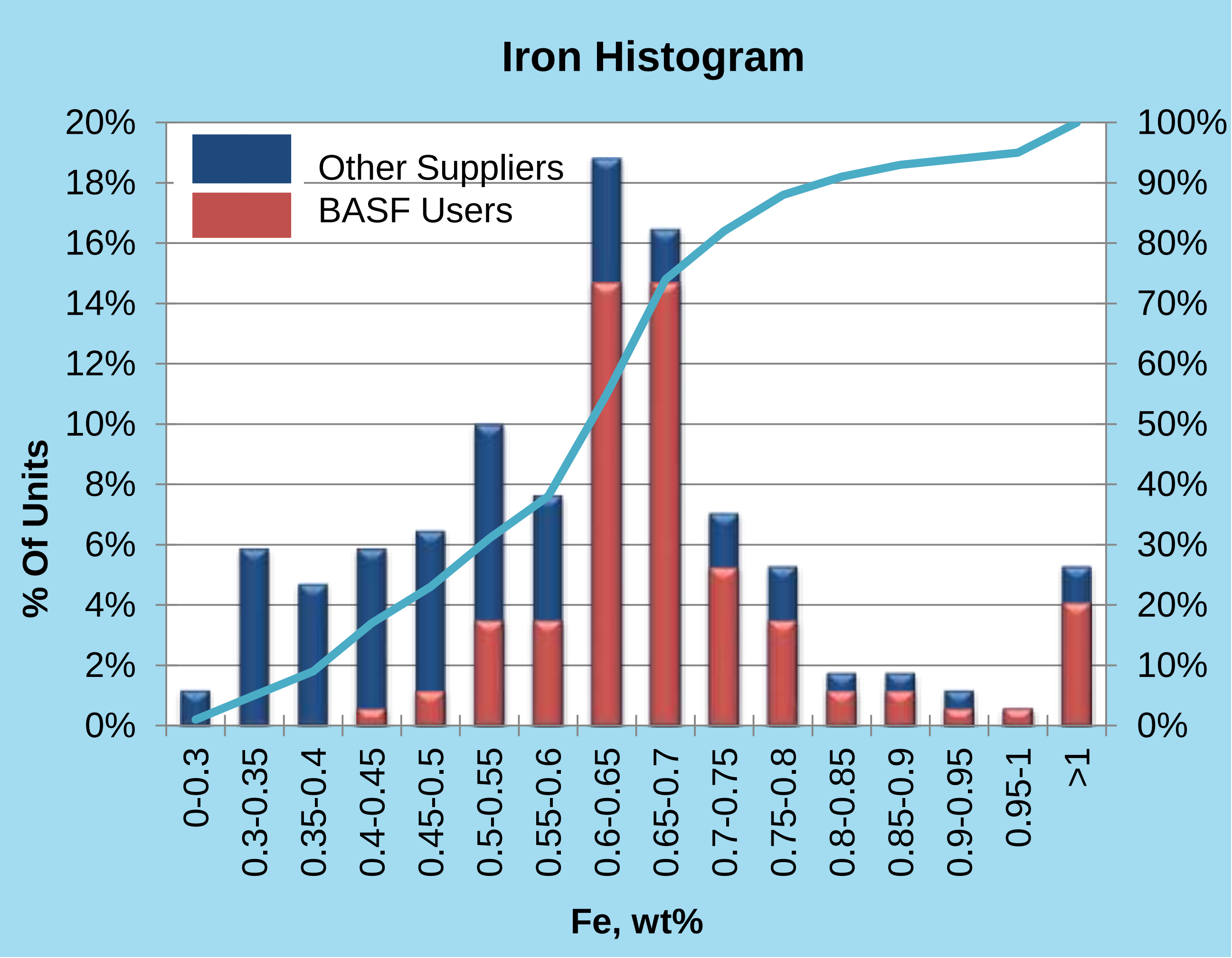
- Some Tight Oils have been shown to contain high iron
- Fe acts as a dehydrogenation catalyst and increases coke and hydrogen yields (1/10th that of Ni)
- Very high levels of iron can produce “iron nodules” which are spike-like protrusions from the surface of the catalyst.
  - Iron nodules formation is indicated by an increase in Fe and reduction of the ECat ABD
  - Very high iron levels can cause pore mouth plugging
    - BASF’s DMS & Prox-SMZ catalysts have good porosity giving them excellent iron tolerance
- Iron will act as a CO promoter, which can cause problems in a partial burn unit



ECat from a unit processing Tight Oil, Fe = 1.5 wt%

High Iron on ECat

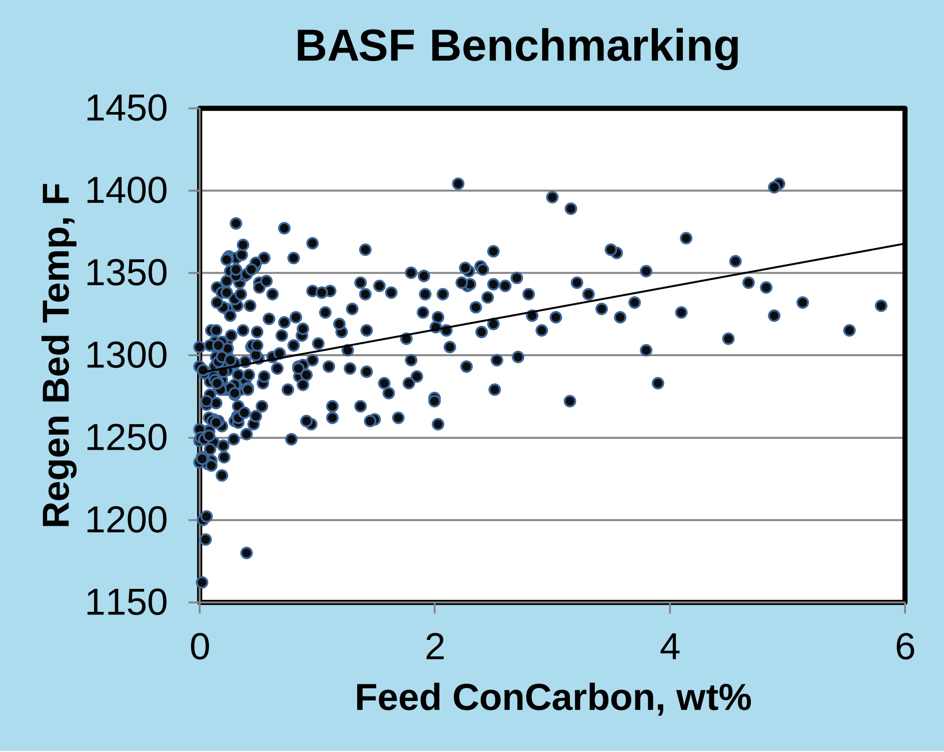
- High porosity catalyst such as BASF's DMS and Prox-SMZ have very high tolerance to iron pore mouth plugging
- One unit successfully ran above 2 wt% iron on ECat with BASF catalyst



Heat Balance Problems

Operating with Lower Regenerator Temp

- Minimum regen bed temperature is set by maintaining stable operation and efficient coke burning, typically 1250-1260°F dense phase
- Rapid operating moves to increase bed temp if needed, all increase delta coke:
  - Increase CO promoter or FCC catalyst additions
  - Reduce partial burn or go into Full burn and reduce excess O2 levels
  - Raise feed preheat
  - Increase O2 injection
  - Increase HCO or slurry recycles
  - <u>Last Resorts</u>
    - Turn on air preheater, check distributor design
    - Add torch oil
    - Reduce dispersion or stripping steam



Longer Term Methods to Increase Delta Coke

Raise the regenerator bed temperature with higher delta coke by:

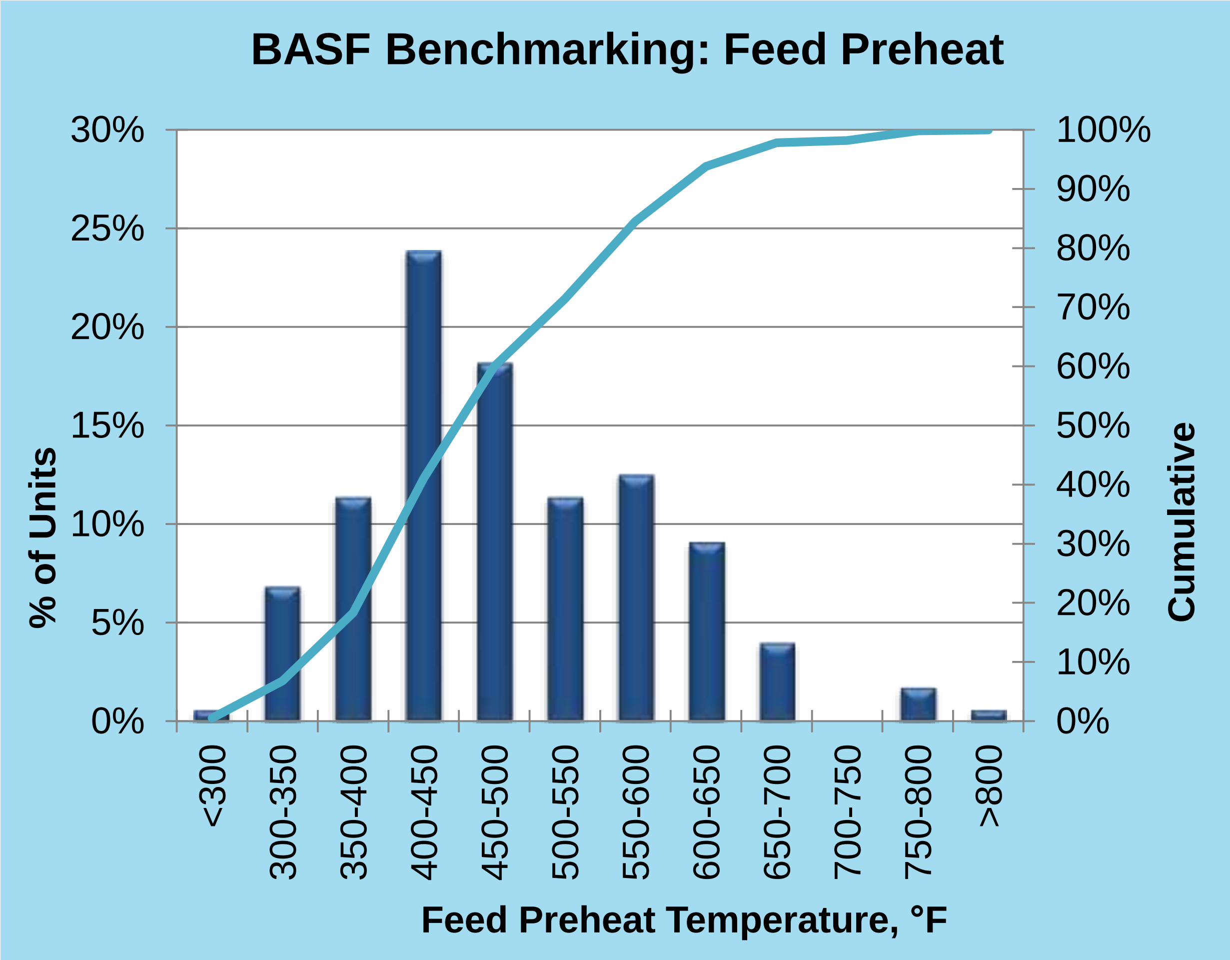
- Feed more resid to the FCC
- Turn down the cat feed hydrotreater
- Increase the catalyst delta coke by
  - Increase catalyst activity through higher cat adds or higher fresh catalyst activity
  - Increase REO
  - Change to a higher delta coke catalyst
- Consider an advanced catalyst management program such as the use of BASF Co-Catalyst Converter® to add in activity in response to the feed quality variability

Catalyst Circulation Limited

- Increase feed preheat
  - If using a FG fired heater, this may provide improved economics over burning coke due to the low price of natural gas
  - Increases liquid yield due to less coke production
  - Maximum preheat set by metallurgical limit and prevention of feed thermal precracking and/or feed vaporization
  - Usually the first, best operational move
- Slide Valve dP Limited
  - Can manipulate vessel bed heights as allowable
  - Consider modifying slide valve port size during next TAR

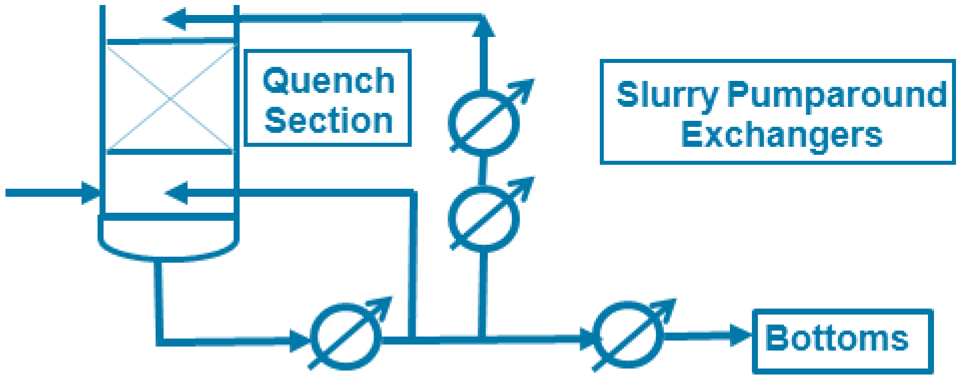
Feed Preheat Benchmarking

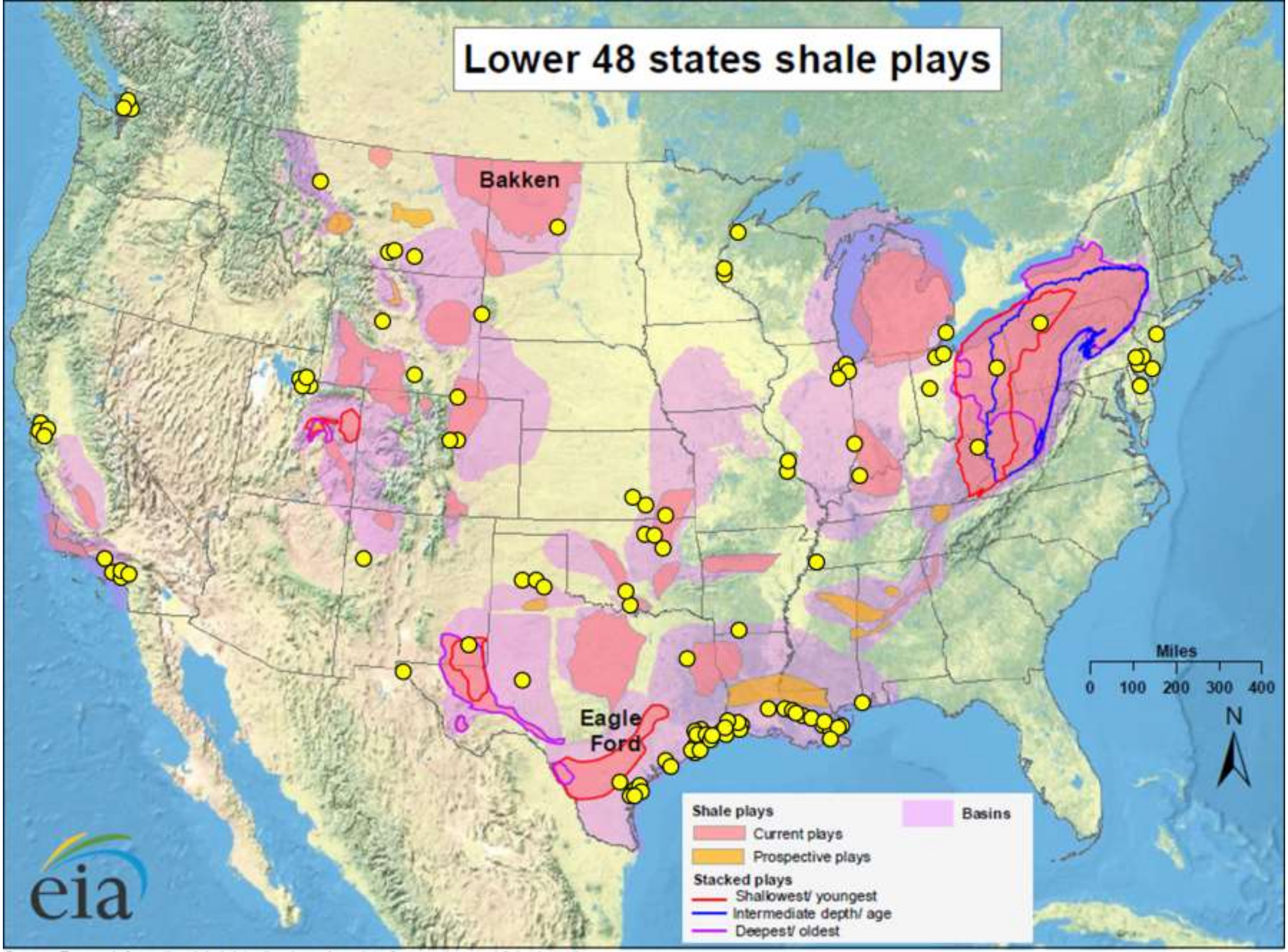
- About 5% of all units are running feed preheat temperatures above 650°F
- Highest Preheat is 805°F



Low Slurry Make

- With low slurry make watch:
  - Slurry ash
  - Slurry velocity for exchanger fouling and line settling
  - Very high residence time in bottom of column due to low yields
  - Keep main column bottom liquid active and well distributed





Source: Energy Information Administration based on data from various published studies.
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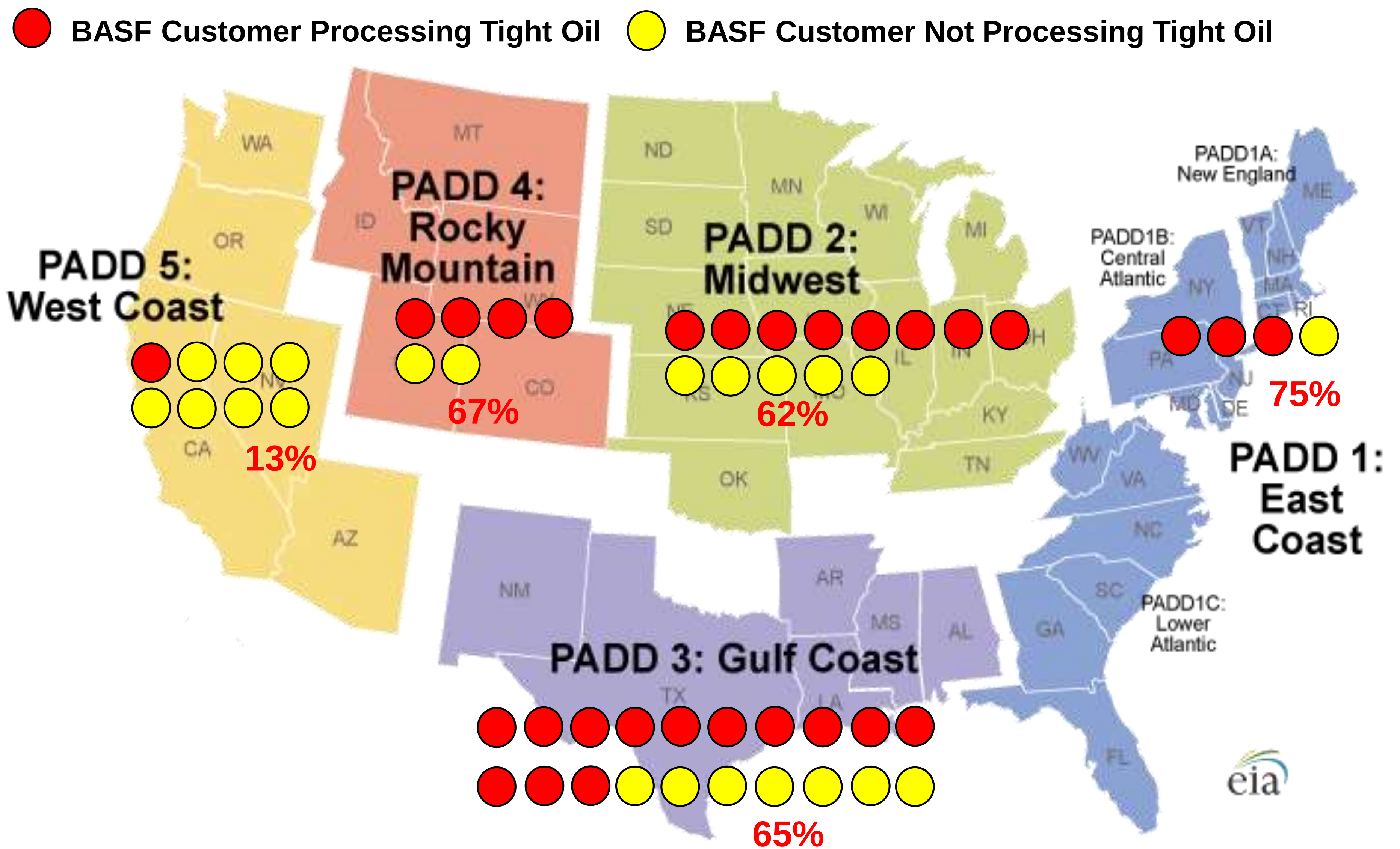
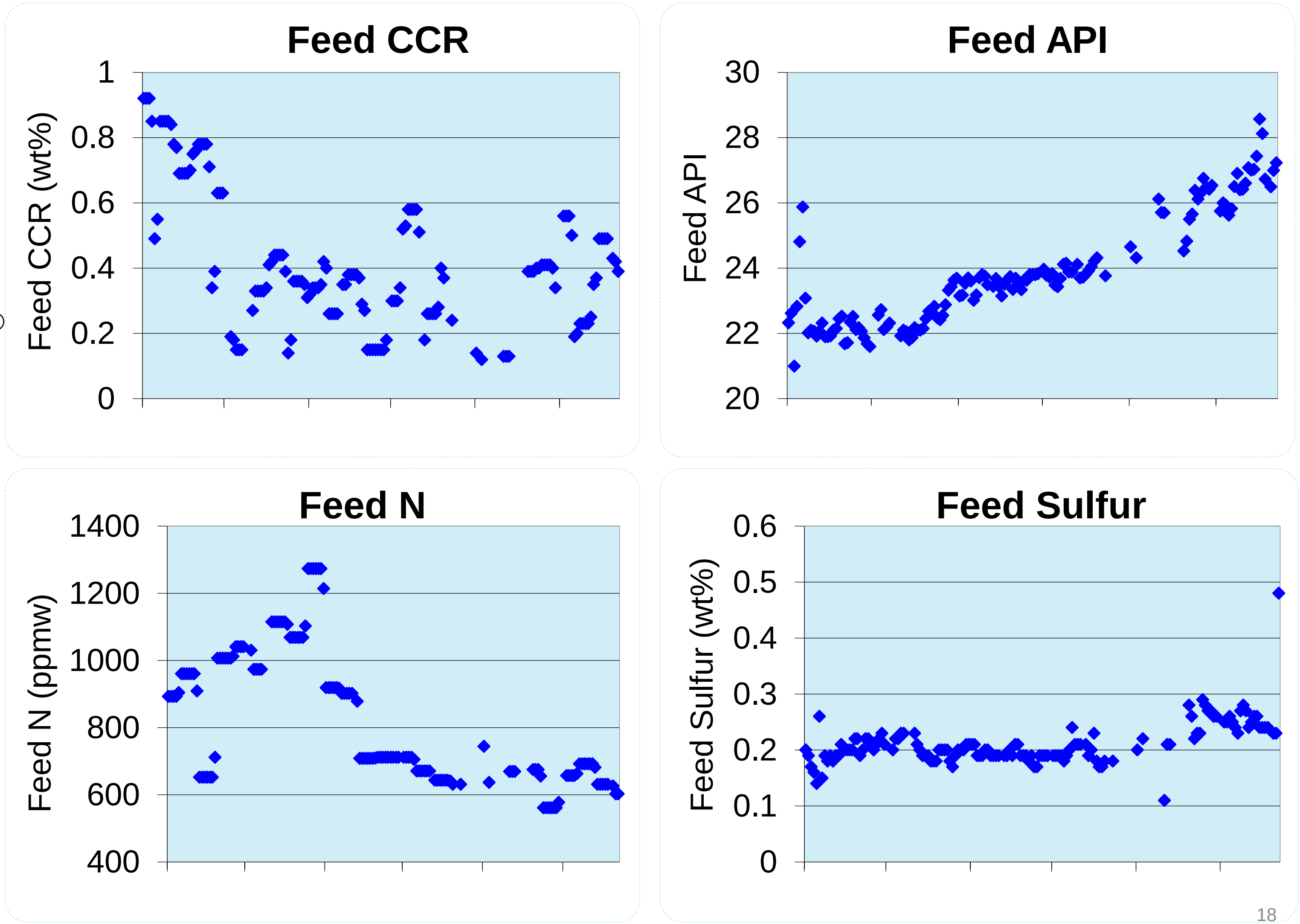


<u>58% of BASF customers have successfully switched to processing tight oil</u>

- Three switched from competitors' catalysts to BASF

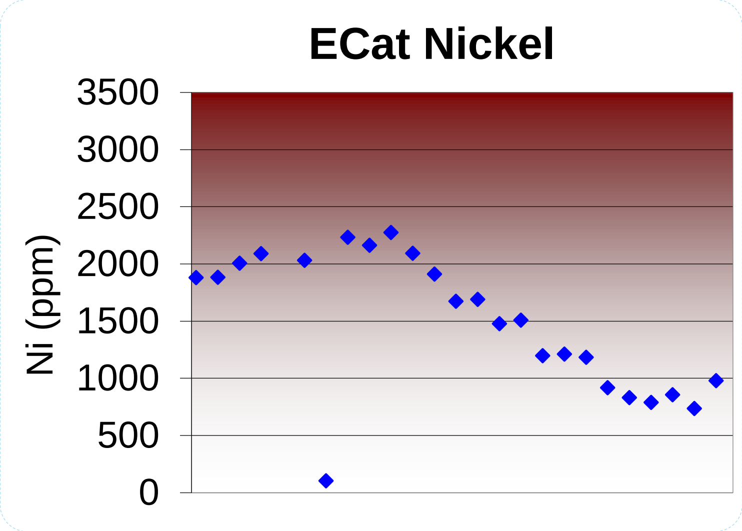
Case #1: VGO FCC Processing Tight Oil

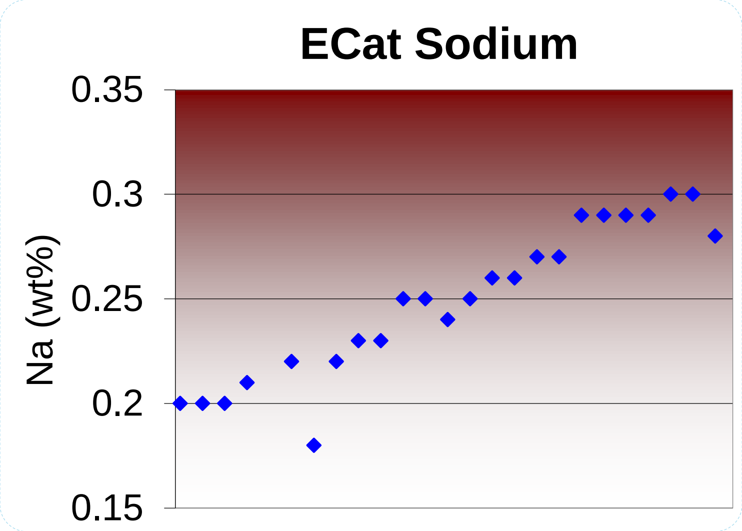
- Gulf Coast unit is running 100% Eagle Ford
- Catalyst: NaphthaMax®
- API gravity increased from 22 to 28
- The lower feed N reduced NOx emissions

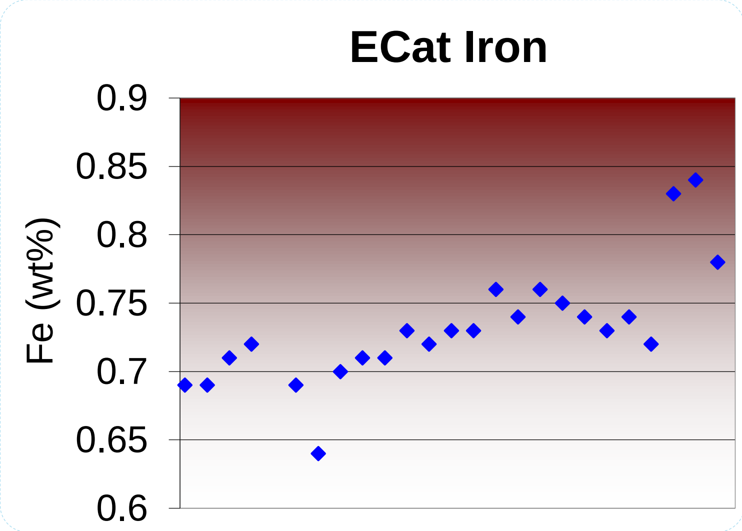


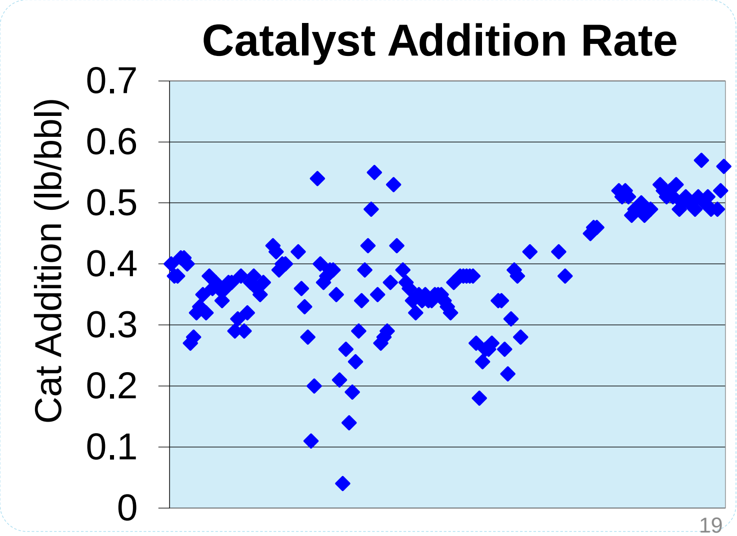
Case #1: VGO FCC Processing Tight Oil

- While metals such as Ni and V decreased, Na and Fe increased
- Ultimately, cat adds were increase 20% to maintain the same ECat activity



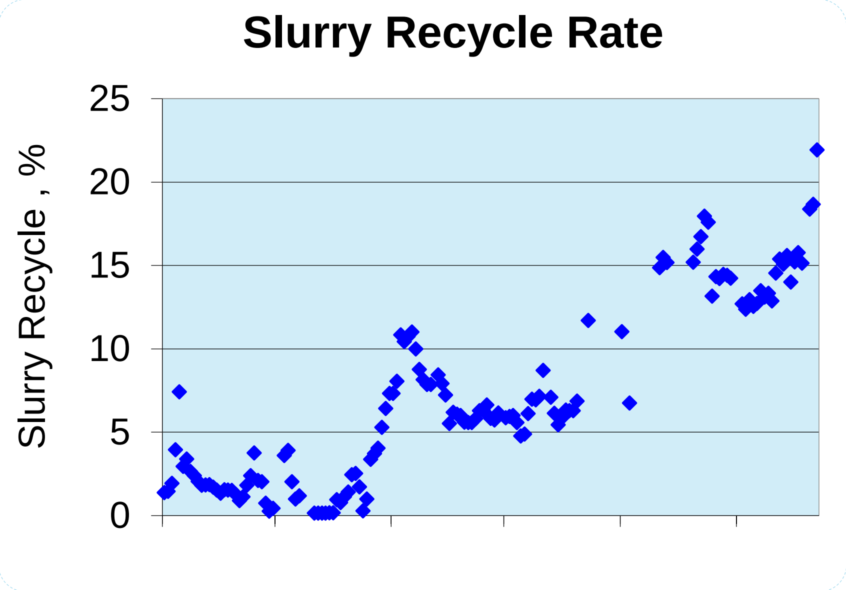


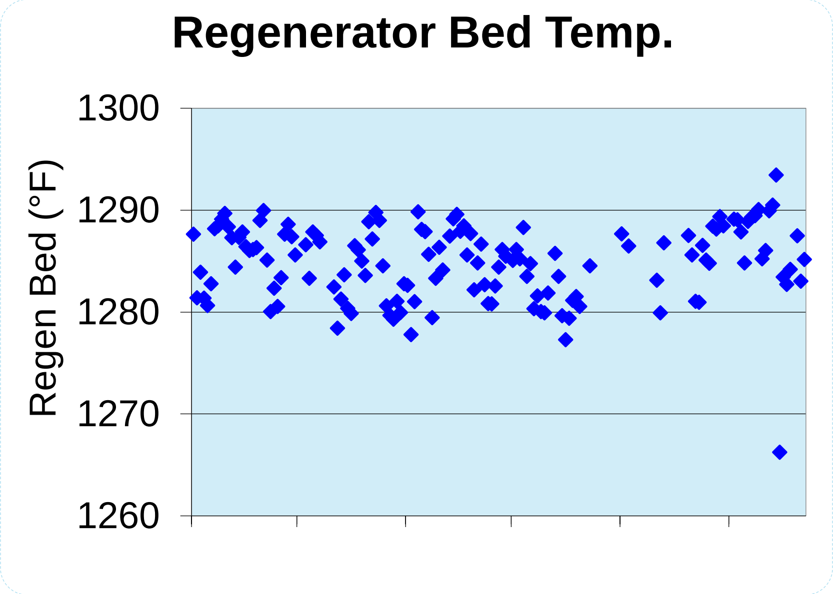




Case #1: VGO FCC Processing Tight Oil

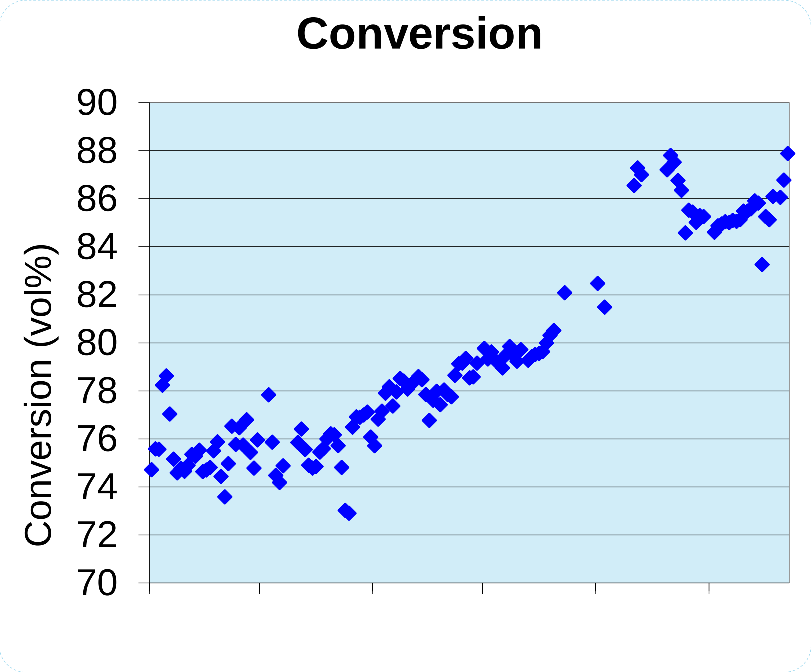
- To maintain regenerator bed temp, slurry recycle was increased to 15%
- No issue with catalyst circulation limit

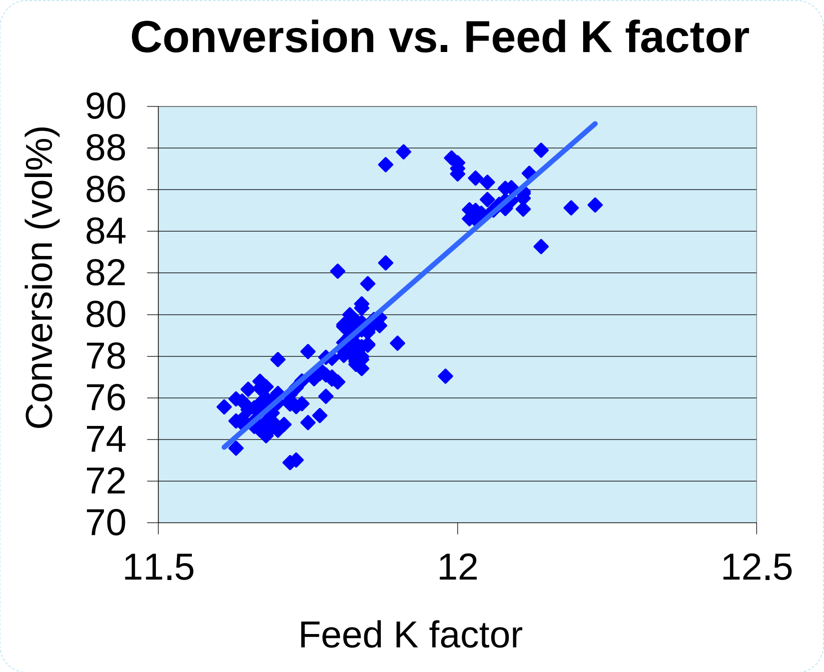




VGO FCC Processing Tight Oil

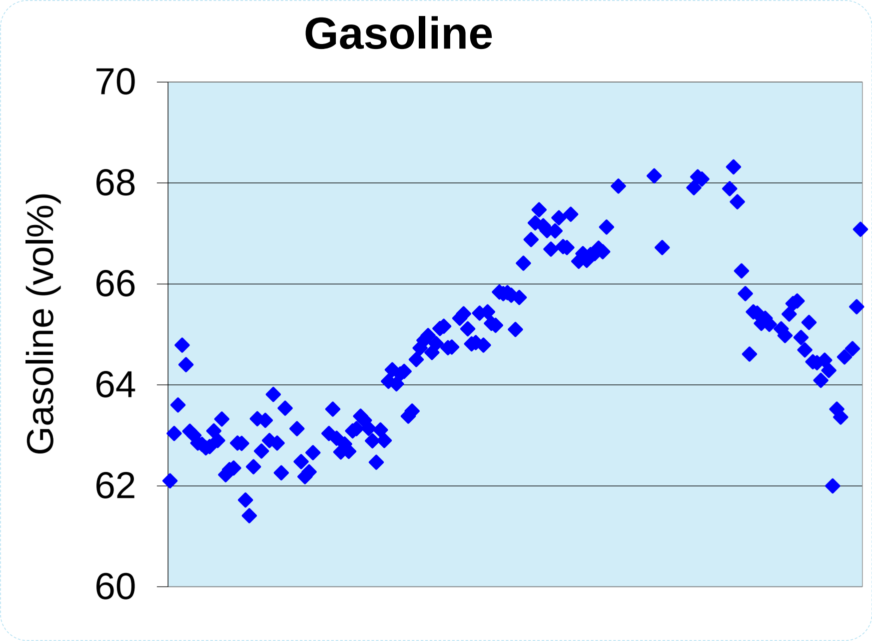
- Conversion increased from 75 vol% to 86 vol% going to 100% tight oil

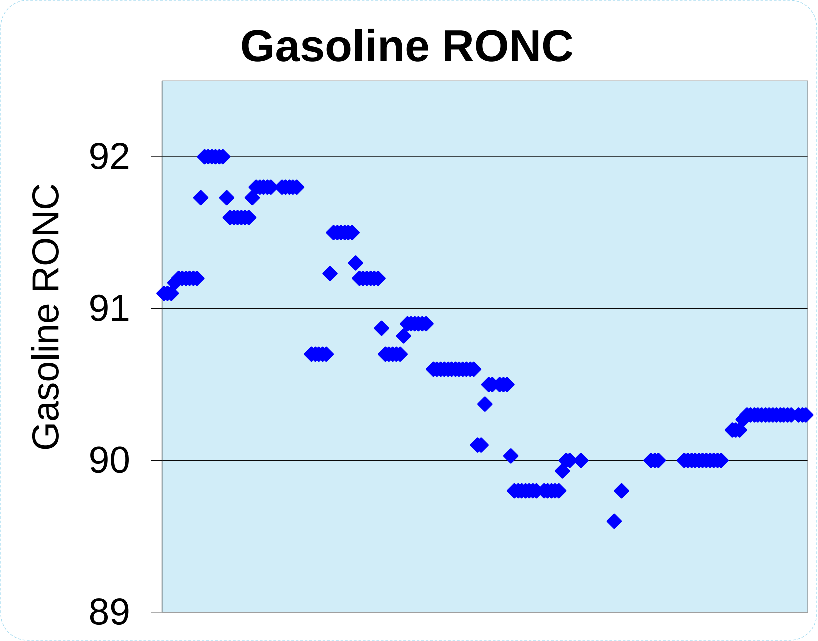




VGO FCC Processing Tight Oil

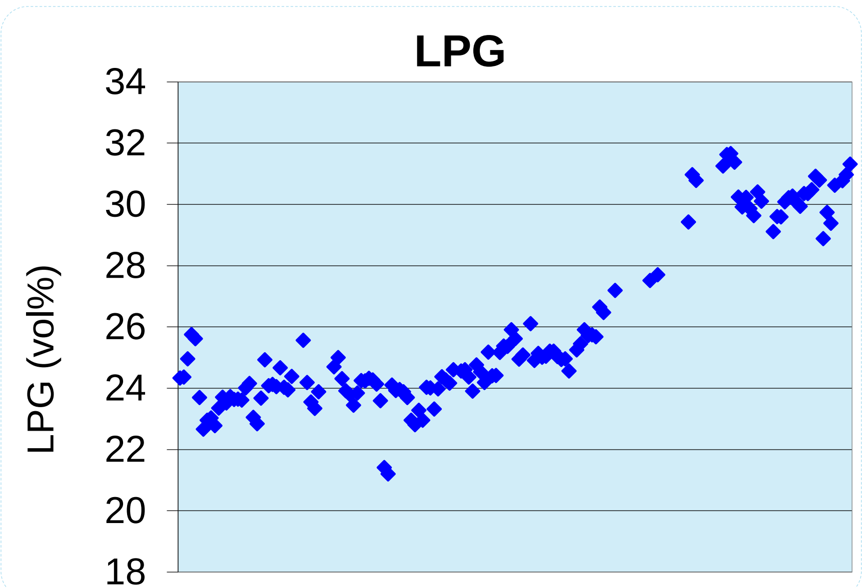
- Gasoline increases, then enters into the overcracking regime
- The gasoline RON decreases as the feed is more paraffinic

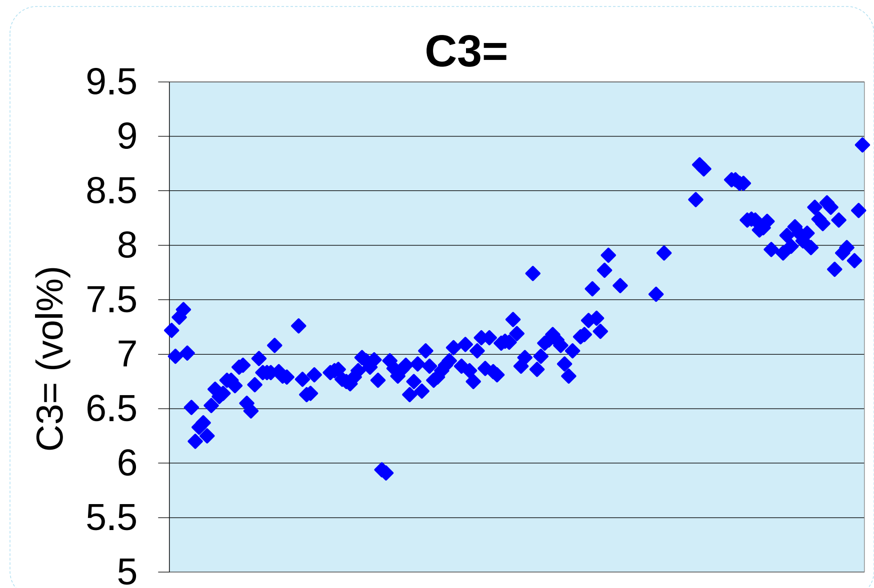




VGO FCC Processing Tight Oil

- Total LPG increased from 24 vol% to 30 vol%
- This large increase in LPG may constrain the gas plant





Case #2:
HT VGO FCC Processing Tight Oil

- This refinery processes VGO, ~70% of which is hydrotreated
- Went to 80% Eagle Ford
- Using BASF's NaphthaMax® II catalyst
- Since it is hydrotreated, properties are similar
  - No major unit operating changes
- Limited by minimum regen temperature

Operation		Base	Change
Feed Gravity	API	26.6	+0.7
Feed Sulfur	wt%	0.5	+0.1
Feed Nitrogen	ppmw	960	-90
Feed Concarbon	wt%	0.16	-
Preheat Temperature	°F	Base	+43
Reactor Temperature	°F	Base	+3
Cat-to-Oil Ratio	wt/wt	5.8	-0.2
Dense Temperature	°F	Base	+3
Catalyst Addition	tons/day	Base	-
ZSM-5 Additions		Yes (5%)	No
Equilibrium Catalyst			
ECat FACT	wt%	77	-
Ni + V	ppm	1500	+50
Fe	wt%	0.62	-
Na	wt%	0.19	-0.01

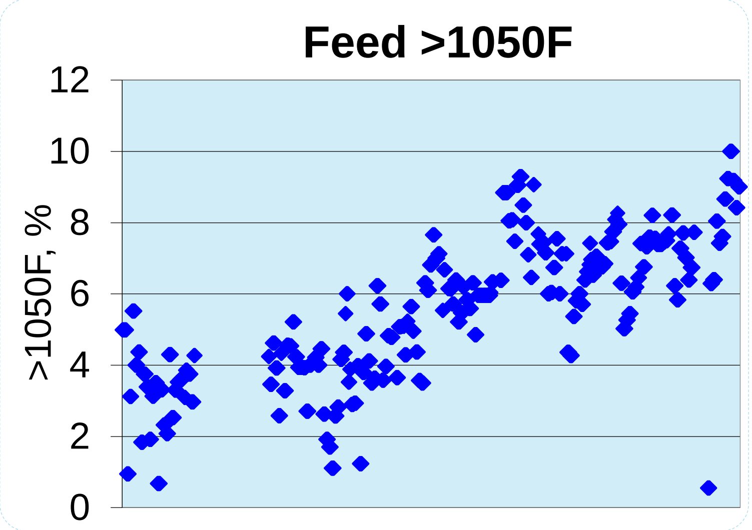
Case #2:
HT VGO FCC Processing Tight Oil

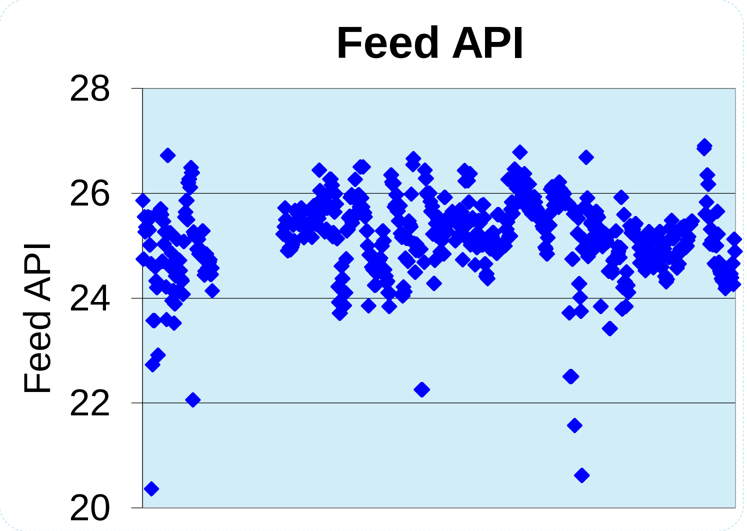
- Conversion increased
- Lower dry gas and coke
- Despite ZSM-5 being removed, the C3= make and total LPG is higher
- Higher total liquid yield
- Unit is operating very well with NaphthaMax® II catalyst with no need to make a catalyst change

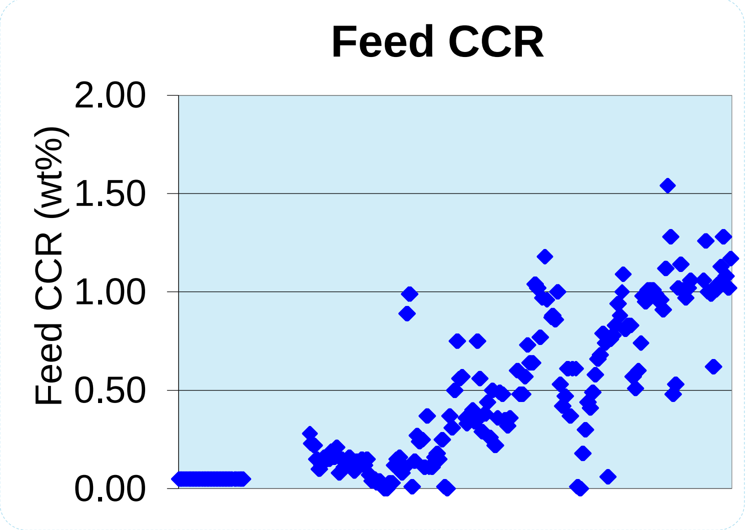
Normalized Yields		Base	Change
Conversion	vol%	80	+2.0
Dry Gas	wt%	1.8	-0.1
C3=	vol%	8.4	+0.4
LPG	vol%	27.7	+0.9
Gasoline	vol%	63.6	+1.9
LCO	vol%	15.3	-1.7
Slurry	vol%	4.8	-0.3
Coke	wt%	4.10	-0.05
Total Liquid Yield	vol%	111.3	+0.9

Case #3:
Mild Resid FCC Processing Tight Oil

- Prior to the introduction of Bakken, the FCC ran VGO
- The lack of VGO in Bakken resulted in extra FCC capacity, to fill this extra capacity the refinery sent resid to the FCC which improved economics for the refinery
- CCR increased from 0 to 1 wt%, and the 1050F+ fraction doubled
- Changed catalyst from BASFs NaphthaMax® to Fortress™ for excellent metals tolerance

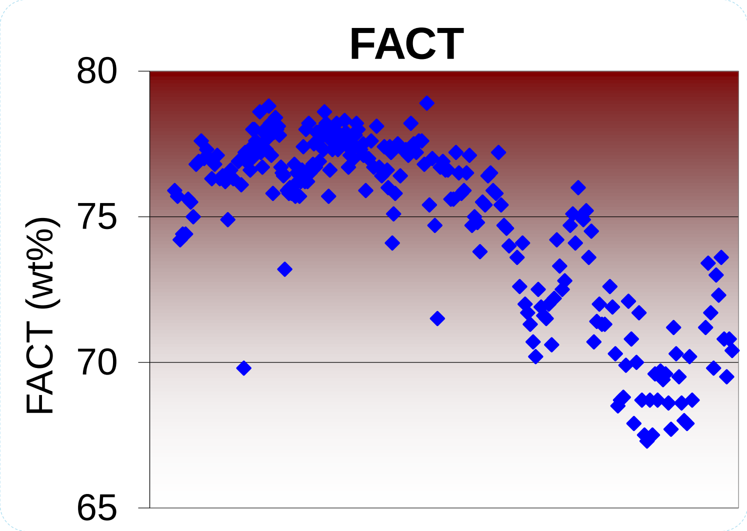


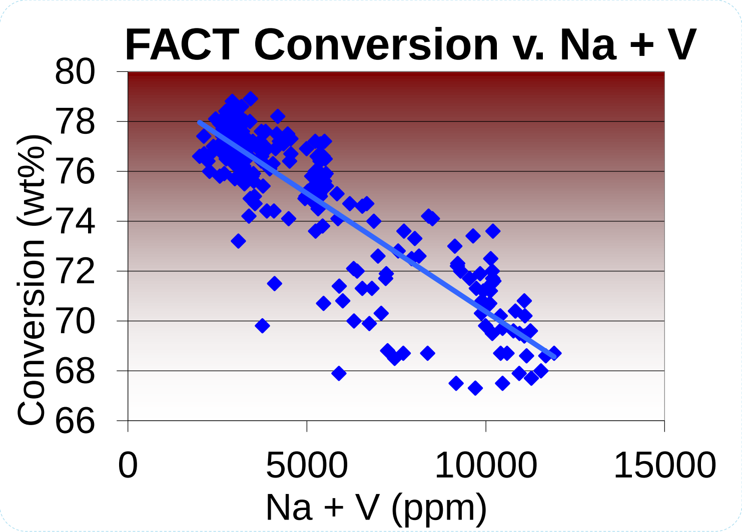


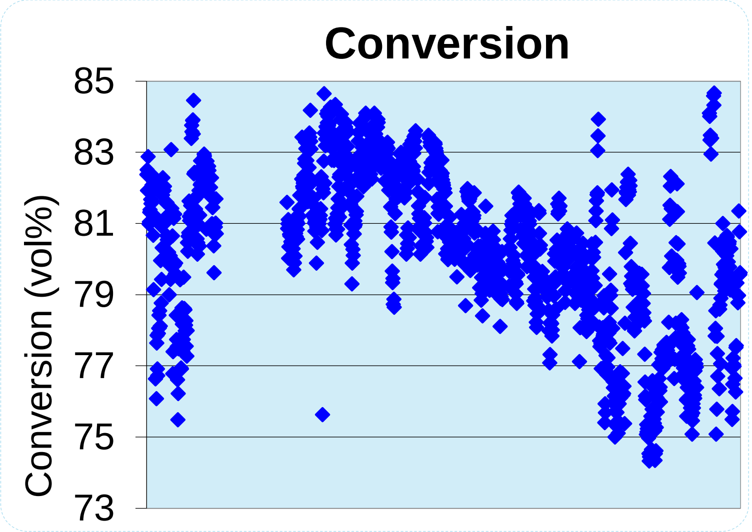


Case #3: Mild Resid FCC Processing Tight Oil

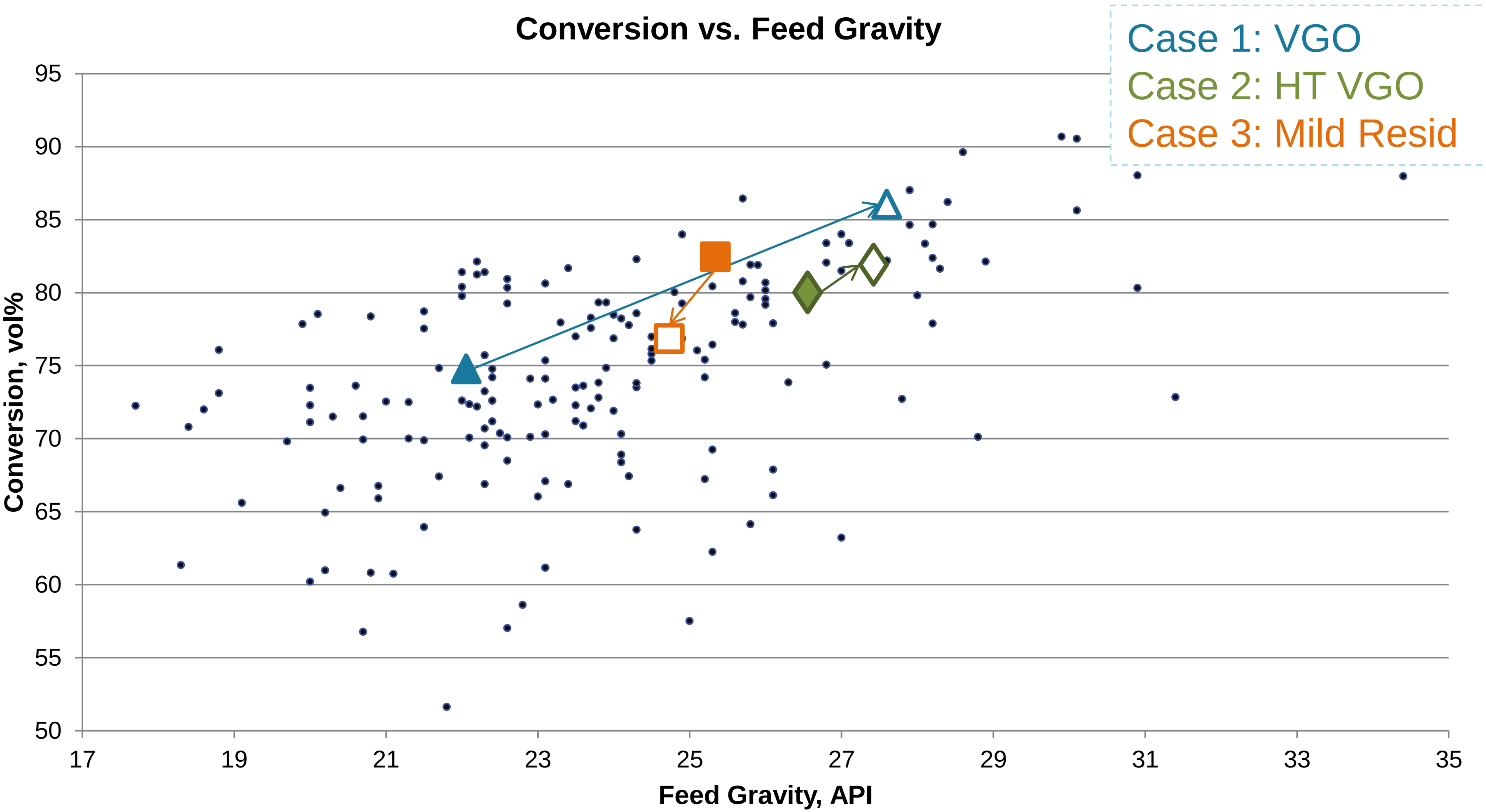
- Due to the high contaminant levels the catalyst activity fell 7 numbers with 25% higher cat adds
- Conversion decreased from 82 vol% to 77 vol%
- The high contaminant levels of Na and Ca may lead to high corrosion rates in the unit







Benchmarking Operations



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Optimizing Value

Assuming Tight Oil feed and typical Gulf Coast Economics

- Maximize Conversion over LCO, Also many tight oils have more straight run diesel which also reduces the need to maximize LCO from the FCC
- Maximize LPG= selectivity: C3= and C4= continue to be valuable, while LPG saturates are not. Balance catalyst activity, REO level and ROT to increase the LPG olefinicity. Consider using ZSM-5 if the gas plant has room.
- Increase Gasoline Octane: Very high octane values of over $2/bbl are being seen in the Gulf Coast (likely due to the low octane of the SR gasoline from the tight oil). Lower REO and ZSM-5 typically will both improve the economics despite the gasoline loss, but the increase in LPG may not be feasible
- Maximize Preheat: it is more economical to burn NG then make coke to keep the FCC in heat balance
- Catalyst Management: More proactive catalyst management due to the variability of the feed
- Contaminants: High alkali metals and iron requires proper catalyst management

Wide Variety of Catalysts Used in Tight Oil Application

Gas Oil Max Conversion
- NaphthaMax®
- NaphthaMax® II
- NaphthaMax® III
- PetroMax™

Gasoil Max Distillate Units
- HDXtra™

Resid Max Conversion Units
- Endurance®
- Flex-Tec®
- Fortress™

Resid Max Distillate Units
- Stamina™

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Summary

- Advantaged tight oil production will continue to rise in North America, providing economic feedstocks to US refiners
- FCCs processing tight oil generally experience
  - Higher conversion
  - Circulation constraints
  - Minimum regenerator temperatures
  - Higher alkali and iron contaminant

- FCC catalyst technology and service must be flexible to meet the changing feed quality and operating conditions associated with the crude
  - There is no universal catalyst solution for tight oil
- BASF is the market leader for tight oil FCC applications providing catalyst solutions to meet the unique challenges of processing tight oil

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