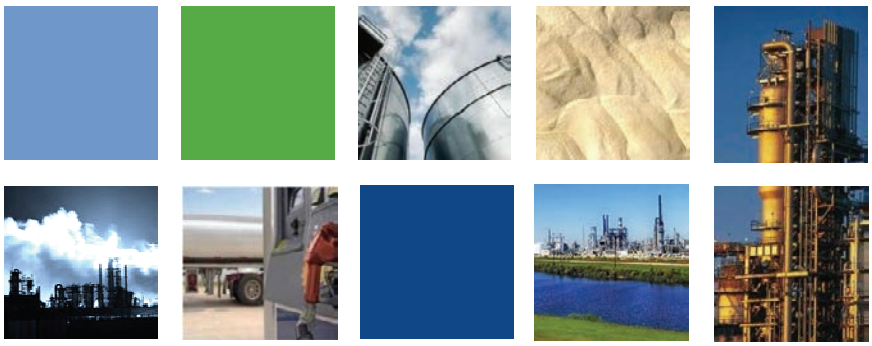

Optimizing Operations in a High Rare-Earth Cost World

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Outline

- Rare-Earth Market: Supply and Demand
- Use of Rare Earth in FCC catalyst
- Case Study
  - Catalyst options with lower rare earth
  - Impacts on operation
- Conclusions

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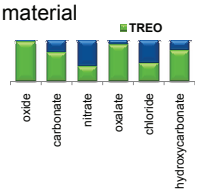
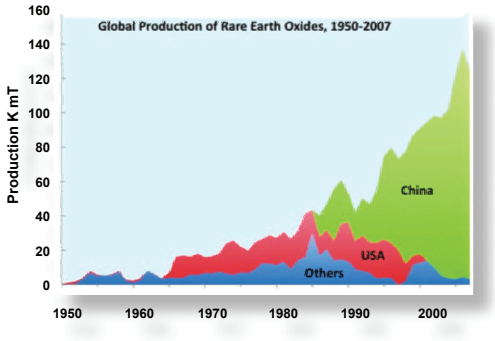
Major Rare Earth Supplier is China

- 97% of world output
- Dominant supplier since the 90's
- Export quotas restrict supply
  - Decreased 50% since 2009
  - Quota needed for every pound of material



- Consolidation reduces suppliers
- Environmental compliance investment adds cost



Credit: ACS, Du and Graedel.

Limited short term options for supply outside of China
Development of new sources will take 5-10 years

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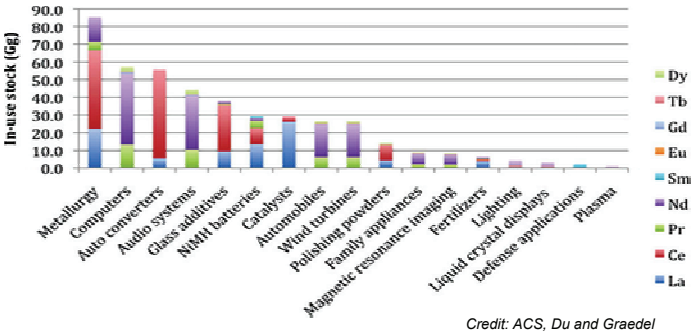
Rare Earth Metals are Key Raw Materials in Many Industries

- "Green" technologies (hybrid cars, wind turbines, energy-efficient lighting)
- Military applications (guidance systems)
- Lightweight electronic components (cell phones, music devices, flat panels)
- Automotive (catalytic convertors, glass, motors)
- FCC catalysts (activity and metals trapping), FCC environmental additives
- Substitutes do not exist for many applications



Credit: ACS, Du and Graedel

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Future Rare Earth Metals Demand

- La and Ce are forecasted to be in oversupply
- China could become a net importer by 2015?
- End users are actively searching for alternatives which may ease some demand in the near future.

Table 22: Forecast global demand for individual Rare Earths in 2014 (±15%)

REO	Total Supply	Demand	Balance	Balance as % of demand
Lanthanum	54,750	51,050	3,700	7.25
Cerium	81,750	65,750	16,000	24.33
Praseodymium	10,000	7,900	2,100	26.58
Neodymium	33,000	34,900	-1,900	-5.44
Samarium	4,000	1,390	2,610	187.77
Europium	850	840	10	1.19
Gadolinium	3,000	2,300	700	30.43
Terbium	350	590	-240	-40.68
Dysprosium	1,750	2,040	-290	-14.22
Erbium	1,000	940	60	6.38

Source: Lanthanide Resources and Alternatives, Oakdene Hollins Research & Consulting – May, 2010

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Use of Rare Earth in FCC

- Rare earth discovered to enhance activity of zeolites in 1960's
  - Control the activity, selectivity and hydrogen transfer of the zeolite
  - Protect zeolite from metals deactivation
- In the 80's and 90's, rare earth free catalysts maximized FCC gasoline octane
- Environmental additives rely upon rare earth for SOx and NOx reduction
- In 90's, FCC rare earth levels increased
  - Improved coke selectivity
  - Metals trapping

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A History of FCC Innovation

1942 – 1st FCC catalyst
1948 – Microspheroidal catalyst
1955 – High alumina catalyst
1966 – Awarded patent for USY process
1985 – SOx transfer additives
1987 – Increased use of coke selective REUSY
1990 – RE free zeolites dominate market
1998 – NOx reduction additives
2003 – IMPACT® catalyst platform
2008 – MIDAS ® catalyst for max LCO
2011 – New zero rare earth FCC catalysts & additives

Rare earth can provide unique functionalities to the FCC operation

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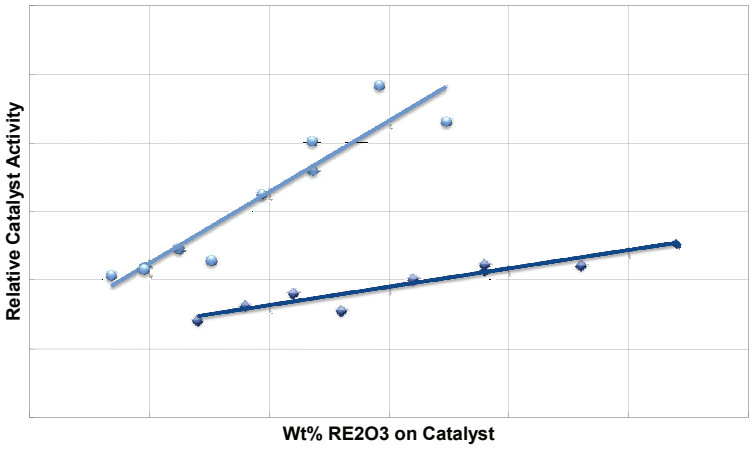
Rare Earth is primary driver for catalytic activity



Catalyst can be formulated to reduced levels of RE, however in-unit activity will be lowered and higher additions may be required.

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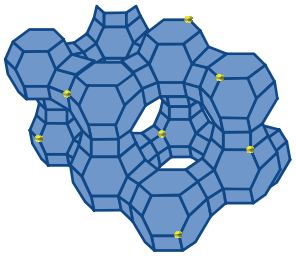
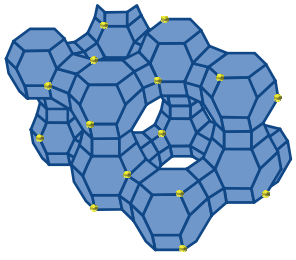
Rare Earth Increases the Zeolite Active Site Density

low unit cell size 24.25 Å
Si/Al = 27
7 Al atoms/unit cell



Moderate unit cell size 24.32 Å
Si/Al = 12
15 Al atoms/unit cell



catalyst	wt% Re2O3 on catalyst	Unit Cell Size (Å)	Conversion, wt% at constant C/O
A	1.1	24.24	53
B	1.8	24.27	65
C	2.2	24.31	69
D	3.3	24.34	73
E	3.7	24.36	76
F	5.7	24.41	80

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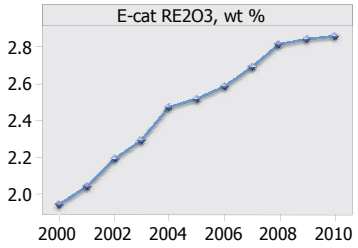
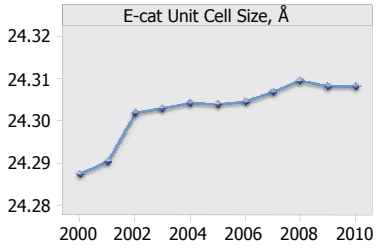
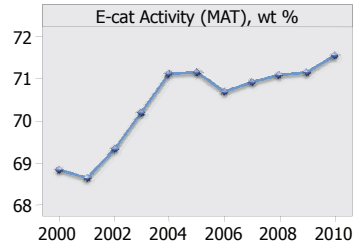
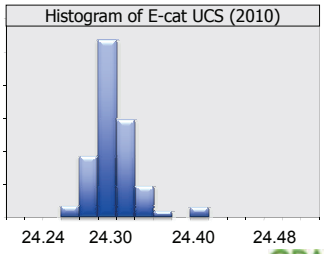
Industry Equilibrium Catalyst Trends 2000-2010









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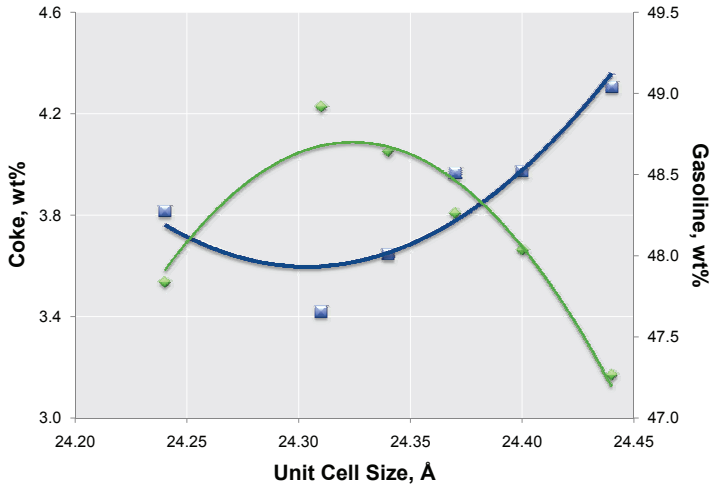
"Sweet Spot" Exists for Catalytic Performance



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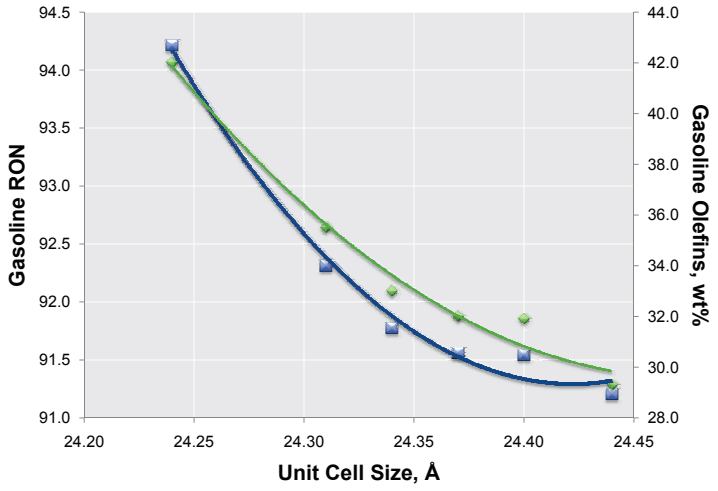
Olefins and RON Decrease with Increasing UCS



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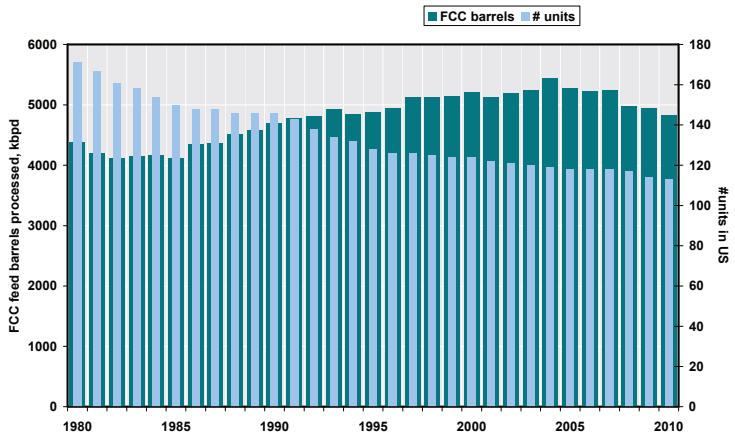
Historical Trends in US FCC Unit Throughput



Capacity grew fastest in the late 80's, early 90's, while use of REUSY also increased

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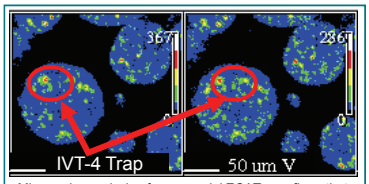
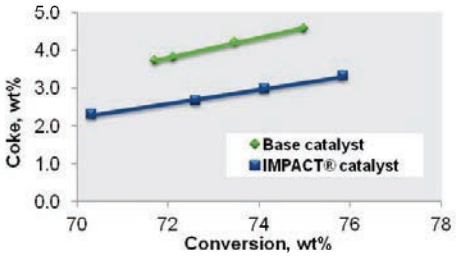
Rare Earth is a Very Effective Metals Trap

- Integral rare earth based metals traps have been confirmed to trap vanadium



Microprobe analysis of commercial ECATs confirms that IVT-4™ is actively trapping V, thus preserving zeolite and selectivities.



Integral rare-earth metals traps enabled many refiners to increase resid processing

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Case Study

- **Operating Objectives**
  - Minimize catalyst costs due to rare earth hyperinflation
  - Maintain or improve total profitability
  - Total liquid yield and LCO are important
- **UOP Side by Side**
  - Modern RTD and FIT
  - Full burn
  - Fired Feed Heater
- **Operating constraints**
  - Air Blower
  - Catalyst Circulation
  - Wet gas at 98% of volume capacity
- **Feedstock Properties**
  - Vacuum Gas Oil
  - 24.1 API
  - 11.7 UOP K
  - 1.3 wt% Sulfur
  - 0.2 wt% ConCarbon
- **Equilibrium Catalyst Properties**
  - 74 wt% Activity
  - 110 m2/gm ZSA
  - 2.6 wt% Rare Earth
  - Unit Cell Size 24.32 Å
  - 470 ppm Nickel
  - 1700 ppm Vanadium
- **Catalyst Additions 5 tpd**

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Fresh Catalyst Properties, Additions and ECAT Activity

Catalyst	BASE
Re_2O_3, Wt.%	2.6
Zeolite SA, m^2/gm	220
Total SA, m^2/gm	290
Catalyst Additions, tpd	5
ECAT Activity	74

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Base Yield and Operating Conditions

Feed Temp, F	600
Reactor Temp, F	992
Regenerator Temp, F	1325
Cat/Oil	6.2
Air Blower	Base
Wet Gas Compressor	Base
Dry Gas, scfb	214
C3=, Vol%	6.3
iC4, Vol%	3.1
C4=, Vol%	7.3
Gasoline, Vol%	54.9
RON/MON	92.5/80.5
LCO, Vol%	28.8

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Economics

- Moderate LCO incentive
- C4= attractive due to volume expansion

Product Value	$/B
Dry Gas	55 ($/FOE)
C3=	85
C4=	105
iC4	80
Gasoline	109
Road Octane Barrel Credit	0.5 (Base 88)
LCO	115
Slurry	65

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Base Fresh Catalyst Properties, Additions and ECAT Activity

Catalyst	BASE	Low Rare Earth
Re_2O_3, Wt.%	2.6	0.7
Zeolite SA, m^2/gm	220	260
Total SA, m^2/gm	290	330
Catalyst Additions, tpd	5	10
ECAT Activity	74	74

ECAT activity must be maintained due to catalyst circulation constraint

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Low Rare Earth Yields and Operating Conditions

Catalyst	BASE	Low Rare Earth
Reactor Temp, F	992	983
Feed Temp, F	600	590
Regenerator Temp, F	1325	1317
Cat/Oil	6.2	6.2
Air Blower	Base	Base
Wet Gas Compressor	Base	1.02 Base
Dry Gas, scfb	214	216
C3=, Vol%	6.3	7.0
iC4, Vol%	3.1	2.7
C4=, Vol%	7.3	7.7
Gasoline, Vol%	54.9	53.1
RON/MON	92.5/80.5	93.3/80.8
LCO, Vol%	28.8	29.7
Product value , $/B (1)	**Base**	**-0.2 $/b**

(1) Product Value includes total catalyst cost

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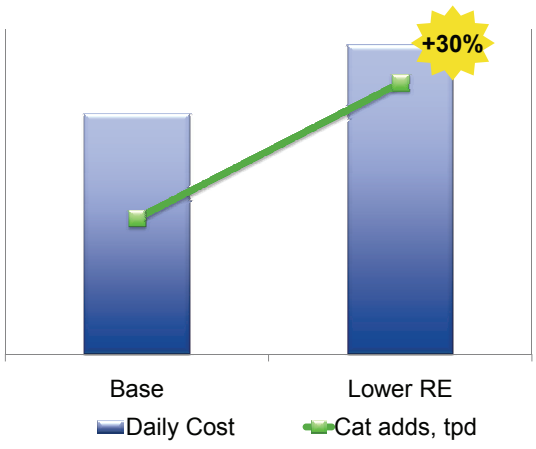
Lowering Rare Earth Can Result in Higher Daily Costs



- Reduce Re2O3 by 75%
- Catalyst $/ton is lower
- Catalyst additions double
- Daily cost increases by 30%

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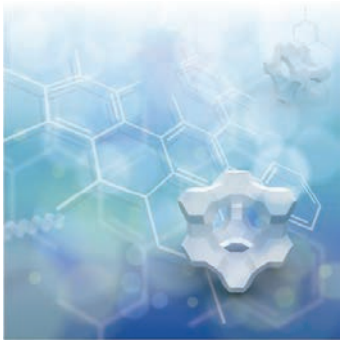
REMEDY™ FCC Catalyst

- Formulated with new RE free zeolites from Grace Davison
  - Proprietary stabilization process
  - Unique treatment step to boost activity
  - Foundation for new family of catalysts
- Delivers similar activity and stability as traditional RE based catalysts
- Performance verified in multiple commercial applications around the globe



REpLa Ce R™

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Fresh Catalyst Properties, Additions and ECAT Activity

Catalyst	BASE	Low Rare Earth	REMEDY™ catalyst
Re_2O_3, Wt.%	2.6	0.7	0.2
Zeolite SA, m^2/gm	220	260	250
Total SA, m^2/gm	290	330	320
Catalyst Additions, tpd	5	10	**5**
ECAT Activity	74	74	**74**

New FCC technology delivers required activity without rare earth

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Optimized Yields and Operating Conditions

Catalyst	BASE	Low Rare Earth	REMEDY™ catalyst
Reactor Temp, F	992	983	988
Feed Temp, F	600	590	595
Regenerator Temp, F	1325	1317	1321
Cat/Oil	6.2	6.2	6.2
Air Blower	Base	Base	Base
Wet Gas Compressor	Base	1.02 Base	1.02 Base
Dry Gas, scfb	214	216	207
C3=, Vol%	6.3	7.0	6.9
iC4, Vol%	3.1	2.7	3.0
C4=, Vol%	7.3	7.7	7.8
Gasoline, Vol%	54.9	53.1	53.6
RON/MON	92.5/80.5	93.3/80.8	93.3/80.9
LCO, Vol%	28.8	29.7	29.2
Product value , $/B (1)	**Base**	**-0.2 $/b**	**+0.4**

(1) Product Value includes total catalyst cost

REMEDY™ ECONOMICS

- **Reduce daily costs by 30%**
- **Increased profitability by $7 mm/yr for a 50,000 bpd FCCU**
  - **Lower dry gas**
  - **Higher C4= & gasoline**

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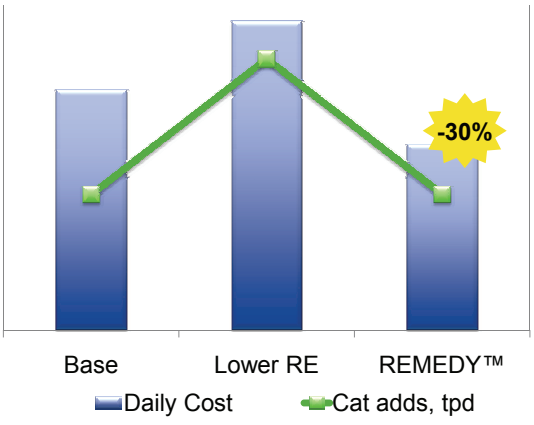
RE-Free Innovations Save Cost and Maintain Performance



- **Reduce Re2O3 by 90%**
- **Maintain activity and catalyst additions**
- **Daily cost decreases by 30%**

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Conclusions

- Rare earth market prices are likely to remain elevated
  - Restricted supply
  - High demand
  - Few viable alternatives exist for most applications
- Activity and stability are critical for economic FCC operations
- Consider all shifts when reformulating to lower Re2O3 on catalyst
  - Total daily cost, not just $/ton
  - Operational impacts
- Technology innovations alleviate the pressure and offer alternatives for rare-earth based FCC catalyst

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Thank you

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