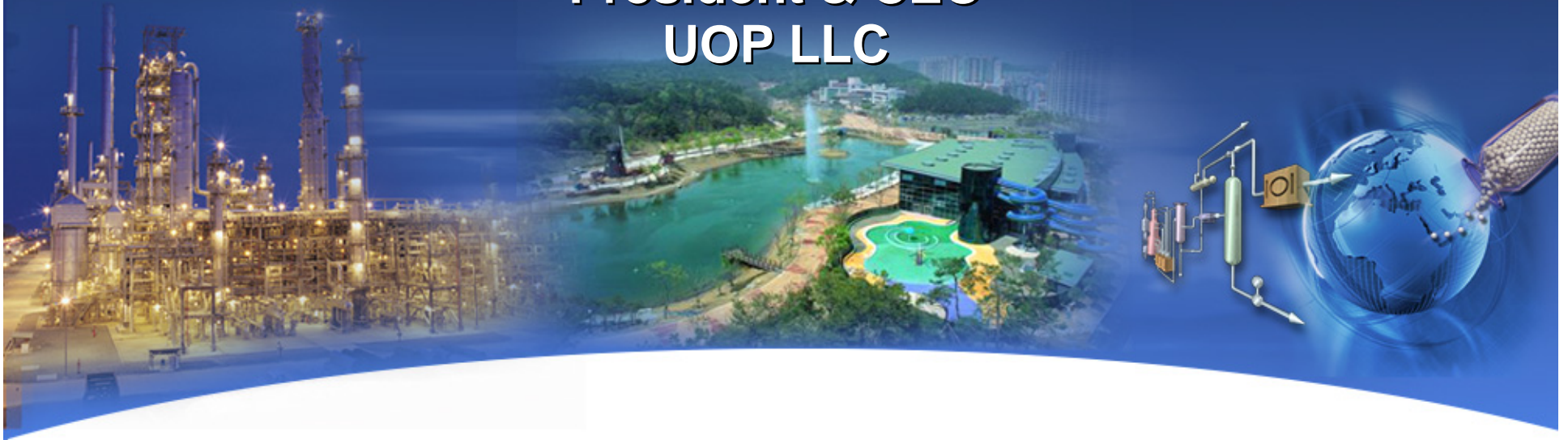


# Chemical Engineering:

## *Technical Challenges: The Last Frontiers*

**Carlos A. Cabrera  
President & CEO  
UOP LLC**

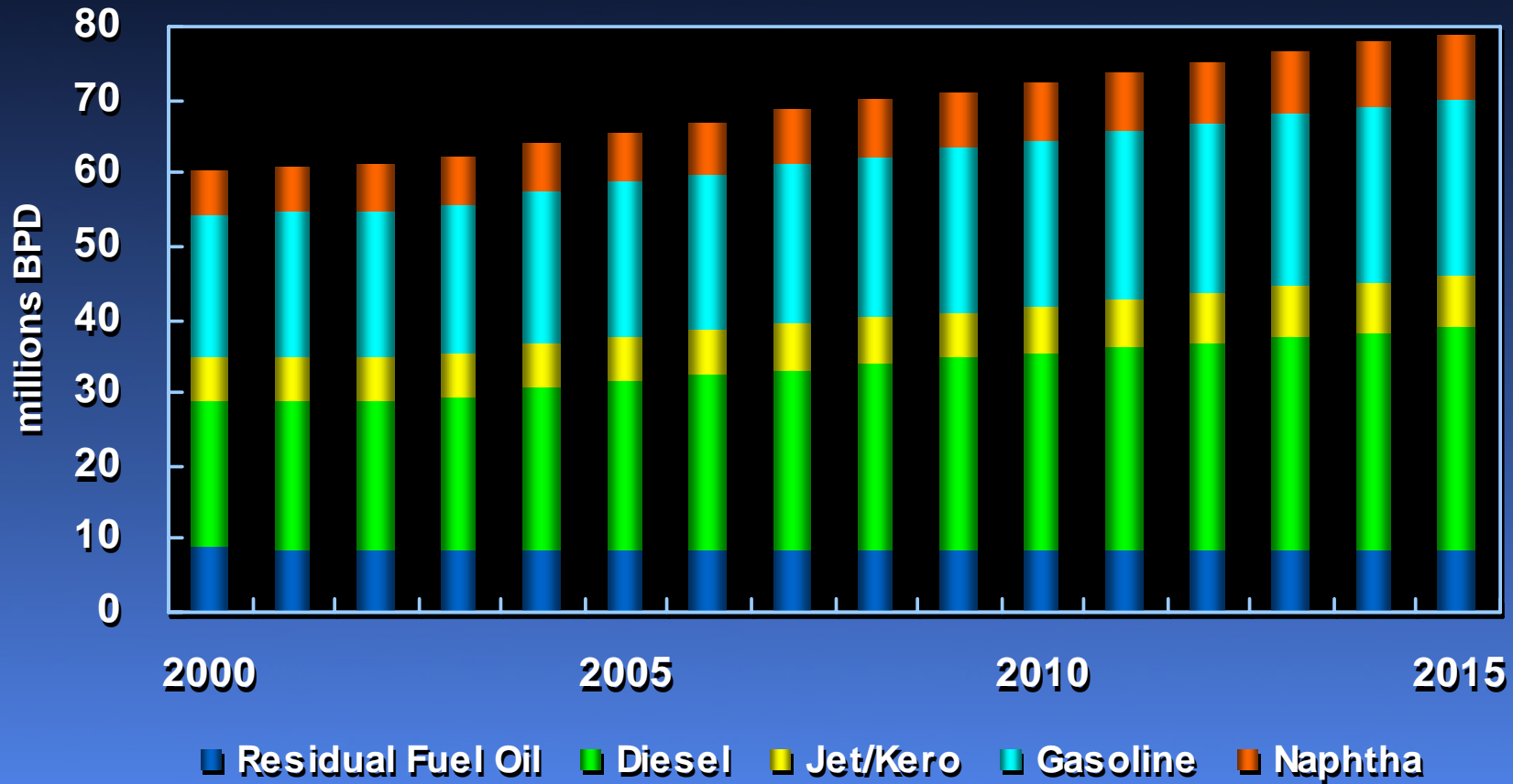


**2008 AIChE Midwest Regional Conference  
September 22**

**Uop**  
A Honeywell Company

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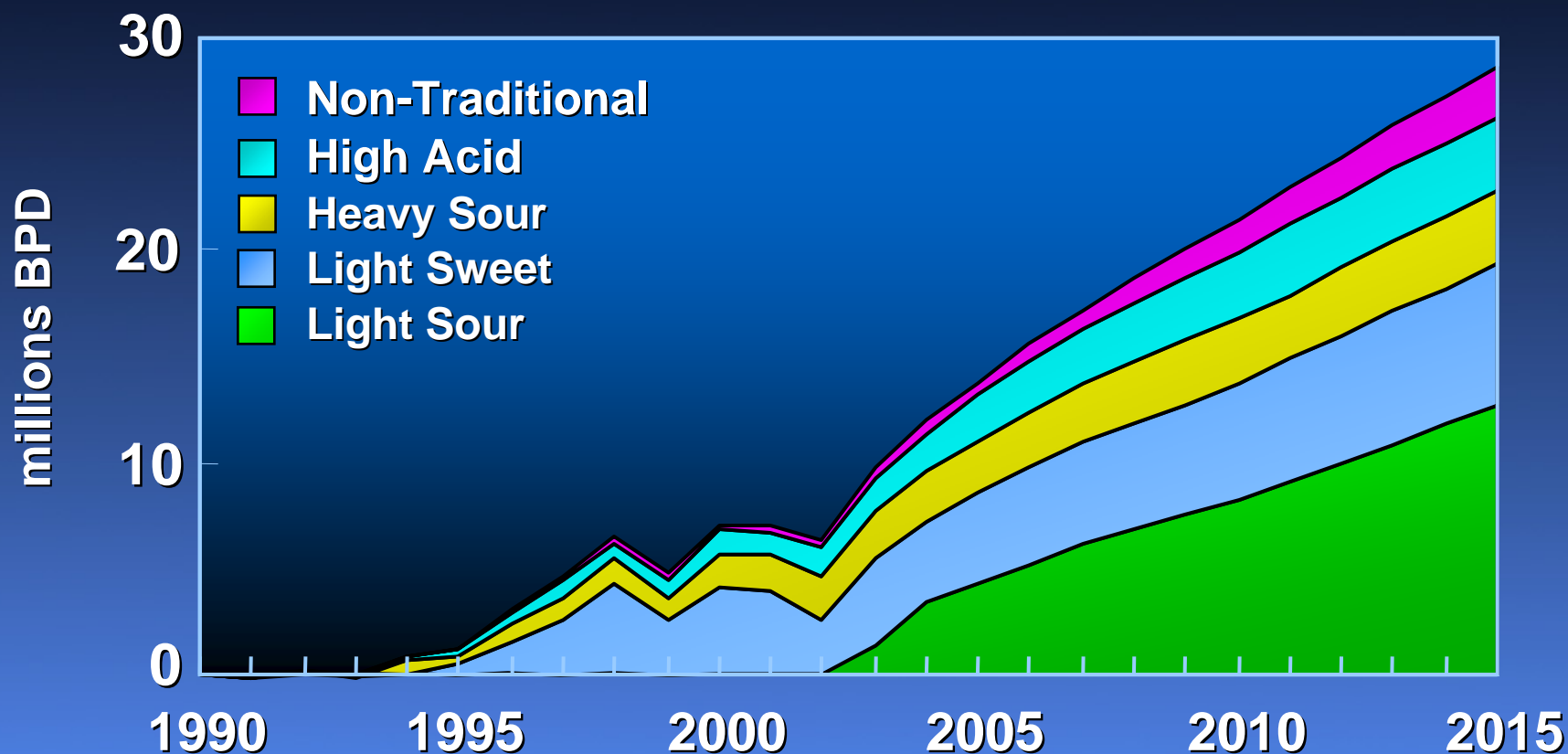
# Global Refined Product Demand



Source: Purvin & Gertz

***Growth is Projected at 1.7% per Annum***

# Incremental Global Crude Oil Supplies

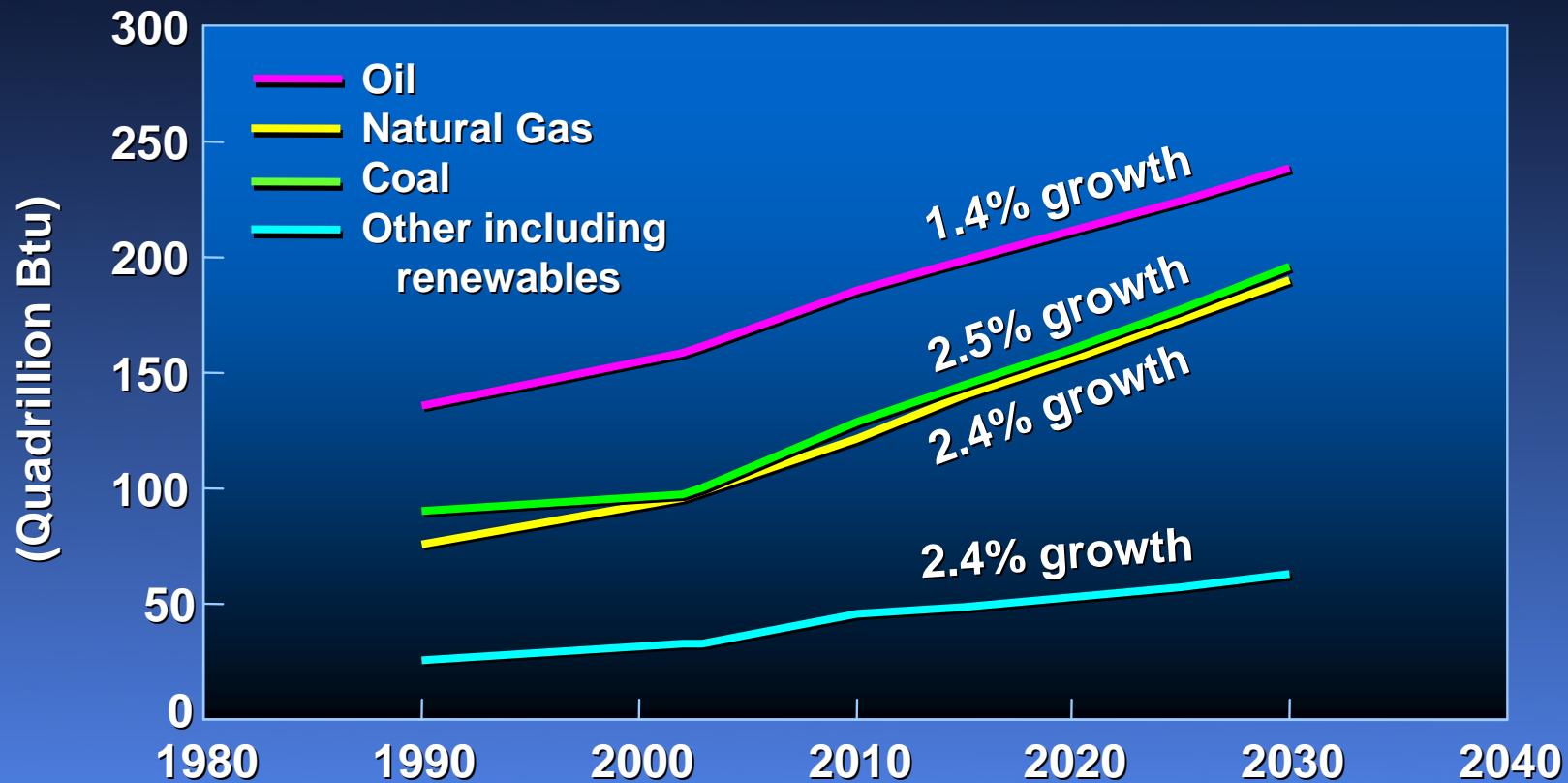


Data supplied by Purvin & Gertz

***10% of the Growth over the Next 10 Years will be Filled with Non-Traditional***

# Non Traditional Fuel & Chemical Sources

## World Total Energy Consumption



Sources: EIA, Annual Energy Outlook 2006, DOE/EIA-0383(2006)

***Coal, Gas and Renewables  
all Growing Faster than Oil***

## CHALLENGES

- Availability, price and declining quality of crude
- Other feedstock availability
- Changing product slates and quality specifications
- New capacity needed to meet forecast demand growth
- Increasing costs of capital projects
- Maintain profitability in a cyclical industry



# Challenges Are Not New in Refining

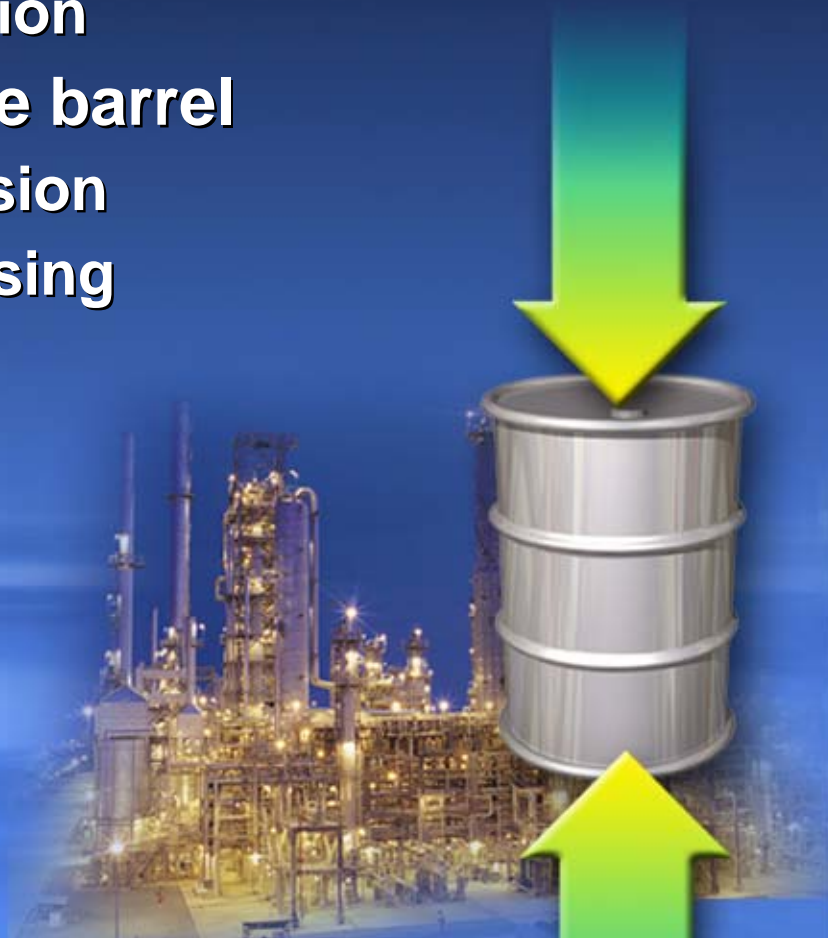
## Challenge

## Response

<b>1900s</b>	<b>Kerosene yield</b>	<b>Dubbs cracking, Houdry cracking</b>
<b>1920s</b>	<b>Gasoline yield</b>	<b>Isomerization, Cat Poly</b>
<b>1940s</b>	<b>Gasoline octane</b>	<b>FCC, Alkylation</b>
<b>1950s</b>	<b>Heavier oils</b>	<b>Hydrocracking, Coking</b>
<b>1960s</b>	<b>Petrochemicals</b>	<b>Steam cracking, Sulfolane, Parex</b>
<b>1970s</b>	<b>Lead phase out</b>	<b>CCR Platforming</b>
<b>1980s</b>	<b>Clean fuels</b>	<b>Ethers, Oleflex</b>
<b>1990s</b>	<b>Lower sulfur</b>	<b>Selective hydrotreating, ULSD HT</b>
<b>2000s</b>	<b>Regulations</b>	<b>MTO, Renewables, Optimization</b>

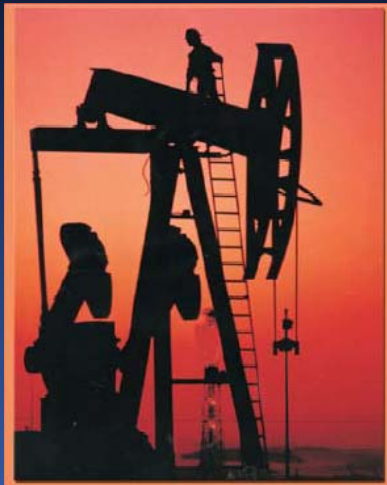
# Technical Challenges: The Last Frontiers

- **The top of the barrel**
  - Methane activation
  - Syngas conversion
- **The bottom of the barrel**
  - Residue conversion
  - Bitumen processing
  - Gasification



# Worldwide Oil, Natural Gas and Coal Reserves

## Oil



1,189 Billion Barrels<sup>1</sup>

## Natural Gas



179 trillion cubic meter  
6,339 Trillion Cubic Feet<sup>1</sup>  
(1,175 bn BOE)

## Coal



909 Billion Tons<sup>2</sup>  
(3,933 bn BOE)

***Natural gas and coal utilization is desired by many companies and nations***

- Monetization of stranded gas reserves and coal
- Reduced gas flaring
- Less dependence on crude oil

1. BP Statistical Review, 2004

2. International Energy Journal, 2003

# C<sub>1</sub> Chemistry: Methane Conversion- UOP is Working on Breakthrough Technology



## Indirect Conversion

## Direct Conversion

Fuels  
& Power

Fischer-Tropsch  
MeOH + MTG

Combustion

Hydrogen

Steam Reforming

Cracking

Aromatization

Chemicals

MeOH Synthesis  
MTO

Oxyhalogenation

Coupling

Direct POX



Demonstrated or  
Existing

To Be Developed /  
Demonstrated

# Direct Methane Conversion Processing Impact on Refining & Petrochemicals



<b><i>CH<sub>4</sub> Conversion Approach</i></b>	<b><i>Primary Products</i></b>	<b><i>Potential Impact</i></b>
<b>CH<sub>4</sub> Aromatization</b> $6 \text{ CH}_4 \rightarrow \text{benzene} + 9 \text{ H}_2$	<b>Benzene, Naphthalene, H<sub>2</sub></b>	<b>With ring opening, makes aromatics or gasoline, large H<sub>2</sub> co-production (9H<sub>2</sub>/ring)</b>
<b>Oxidative Coupling of CH<sub>4</sub></b> $2 \text{ CH}_4 + \frac{1}{2} \text{ O}_2 \rightarrow \text{C}_2\text{H}_4 + \text{H}_2\text{O}$	<b>Ethylene, Ethane</b>	<b>New Source of Ethylene, but huge technical hurdles- limited progress reported in 15 yrs.</b>
<b>Oxy-Halogenation</b> $\text{CH}_4 + \frac{1}{2} \text{ Cl}_2 \rightarrow \text{CH}_3\text{Cl}$ $\text{CH}_3\text{Cl} \rightarrow \text{gasoline} + \text{HCl}$ $4 \text{ HCl} + \text{O}_2 \rightarrow 2 \text{ Cl}_2 + 2 \text{ H}_2\text{O}$	<b>Aromatics &amp; Paraffins or Ethylene + Propylene</b>	<b>CH<sub>3</sub>X can be converted to :</b> - Gasoline or aromatics <u>or</u> - Ethylene and propylene
<b>Direct Selective Oxidation</b> $\text{CH}_4 + \frac{1}{2} \text{ O}_2 \rightarrow \text{CH}_3\text{OH}$	<b>CH<sub>3</sub>OH</b>	<b>Petrochemicals, MTO. Limited progress reported in 15 yrs. Eliminate Syngas production (80% capital for methanol)</b>
<b>New UOP Approach</b>	<b>CH<sub>3</sub>OH</b>	<b>Petrochemicals, MTO Eliminate Syngas production (80% capital for methanol)</b>

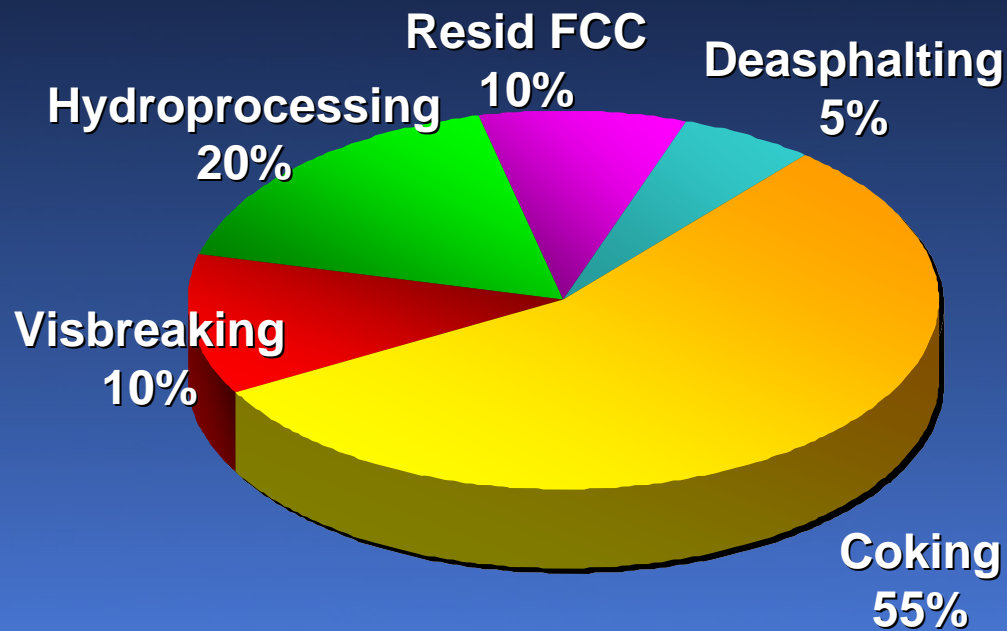
# Extracting More From Heavy Oils

## *Why invest in heavy oil conversion?*

- **Market Factors**
  - Increase transportation fuels
  - Limited residue outlets
  - Bunker fuel regulations
  - Crude availability
- **Economic Incentives**
  - Lower cost of heavier crudes
  - G/D is generally lower in heavy crudes
  - Increased yields of high value products
- **Environmental**
  - Product specifications
  - Refinery emissions



# Residue Upgrading: 1990-2003 Capacity Additions



- Coking and RFCC have dominated last decade
- Future choices dictated by:
  - Market for coke
  - Diesel oriented product slate
  - High specification transportation fuels
  - Crude differentials

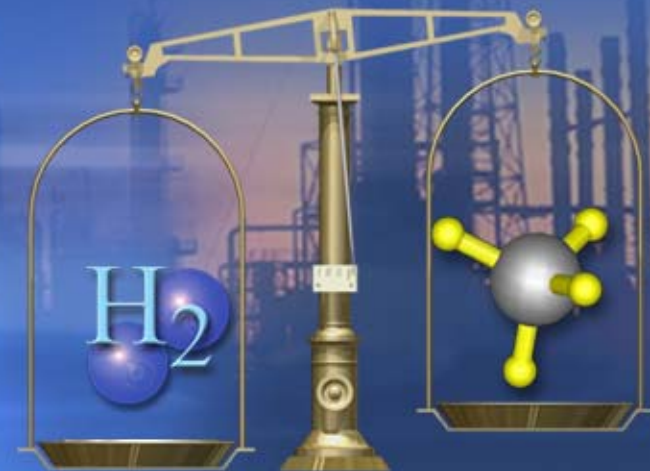
**Total 1990-2003 Residue  
Capacity Addition = 6.5 MM BPSD**

Source: SFA Pacific, UOP Adjusted to VR

# BOB Upgrading Schemes

## *Combining Carbon Rejection and H<sub>2</sub> Addition*

- **Delayed Coking**
  - High Sulfur Coke
  - Low Sulfur Coke
- **Residue Hydrocracking**
- **Solvent De-Asphalting with Hydrocracking**
- **FCC/RFCC with Hydrocracking**
  - With or without Visbreaking



# Challenges of Residue Hydroprocessing

- Sulfur, nitrogen, metals, CCR reduction
- Need for downstream processing to meet product specs
- Catalyst stability
- Investment cost
- Needs reactor and/or catalyst breakthrough



# Other Alternative Feedstocks

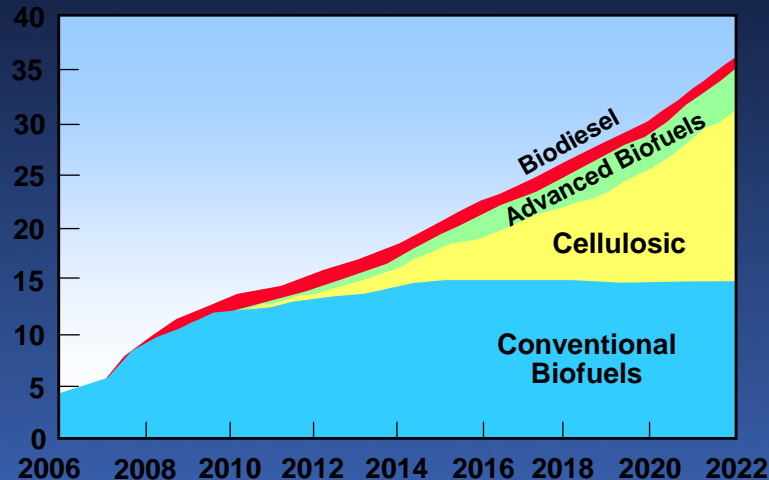
- **Renewables**
  - Vegetable oils
  - Cellulose
  - Sugars
- **Coal**



# Global Government Mandates

## USA: Energy Independence & Security Act (2007)

*Volume and Type of Renewable Fuel Required by the RFS*



- 36 B gallons biofuels, ~2.5 M BPD by 2022
  - Many off-ramps
- Technology neutral
- Corn based ethanol, capped at 15 B gallons
- Emphasis on transition to 2nd generation cellulosics
- Requires demonstration of LCA based GHG savings relative to baseline petroleum fuels

## Europe: Proposed Renewable Energy & Fuel Quality Directives

- 20% of EU Primary Energy Demand from Renewable Sources by 2020
  - Transport Fuels: 10% Renewable Content by energy content
  - GHG Emissions: Fuel producers reduce 10% by 2020 relative to 2010 levels
  - Sustainability targets being put in place

## Global

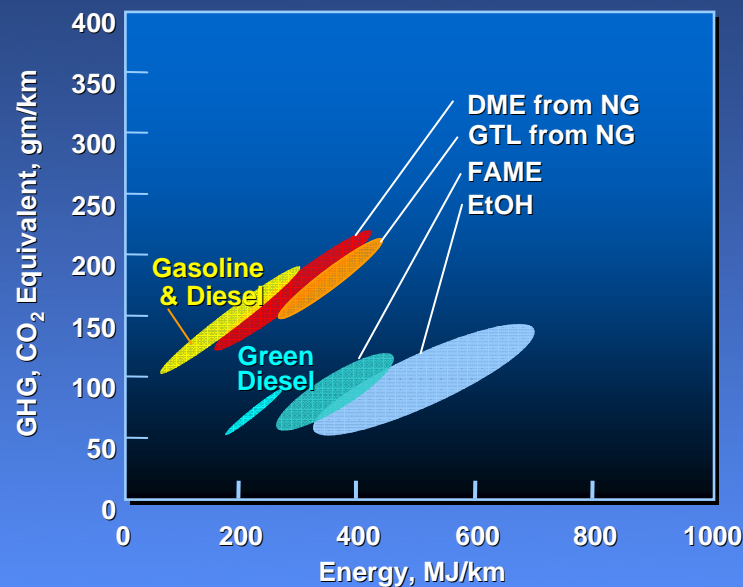
- Countries with B2-B10 and E5-E10 mandates include Canada, Colombia, Peru, Argentina, Thailand, China, India. Brazil is E25.
- Emphasis: non-food

***Increasingly Focused on Sustainability and Second Generation Feedstocks***

# Green Diesel vs. Biodiesel



## WTW Energy /GHG Emissions Clusters



*Green Diesel is Best Biofuel from Energy Consumption and GHG Emissions*

Source: CONCAWE

- **Green Diesel is a better fuel than biodiesel (FAME)**
  - Less energy consumption
  - Less GHG emissions
  - Better economics
  - Better and more compatible fuel properties
- **Wider use of Green Diesel could improve energy efficiency of transportation fuels**
- **Enables much greater use of renewable energy**

# Longer Term Renewables

- **Non-edible fuel crops**
  - Non-edible oil crops: Jatropha
  - High lignin plant wastes
- **Cellulosic biomass**
  - Crop wastes: bagasse, stover
  - Algae



# UOP Biofuels Vision



## *Fuel Additives / Blends*

Ethanol

Biodiesel

## *Fuels*

Diesel

Jet

Gasoline

## *UOP's Bio-Fuels Technology Goals*

Identify and utilize processing, composition, and infrastructure synergies to lower capital investment, minimize value chain disruptions, and reduce investment risk.



### *Generation 1*

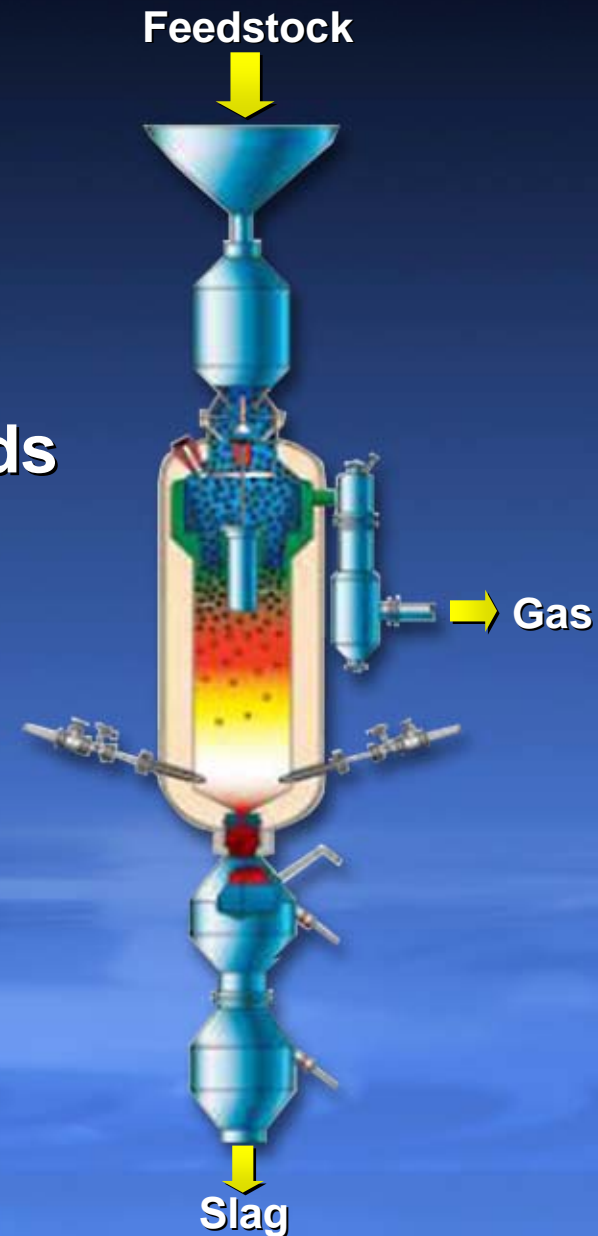
- Natural oils, fats, greases to diesel, gasoline and jet fuel

### *Generation 2*

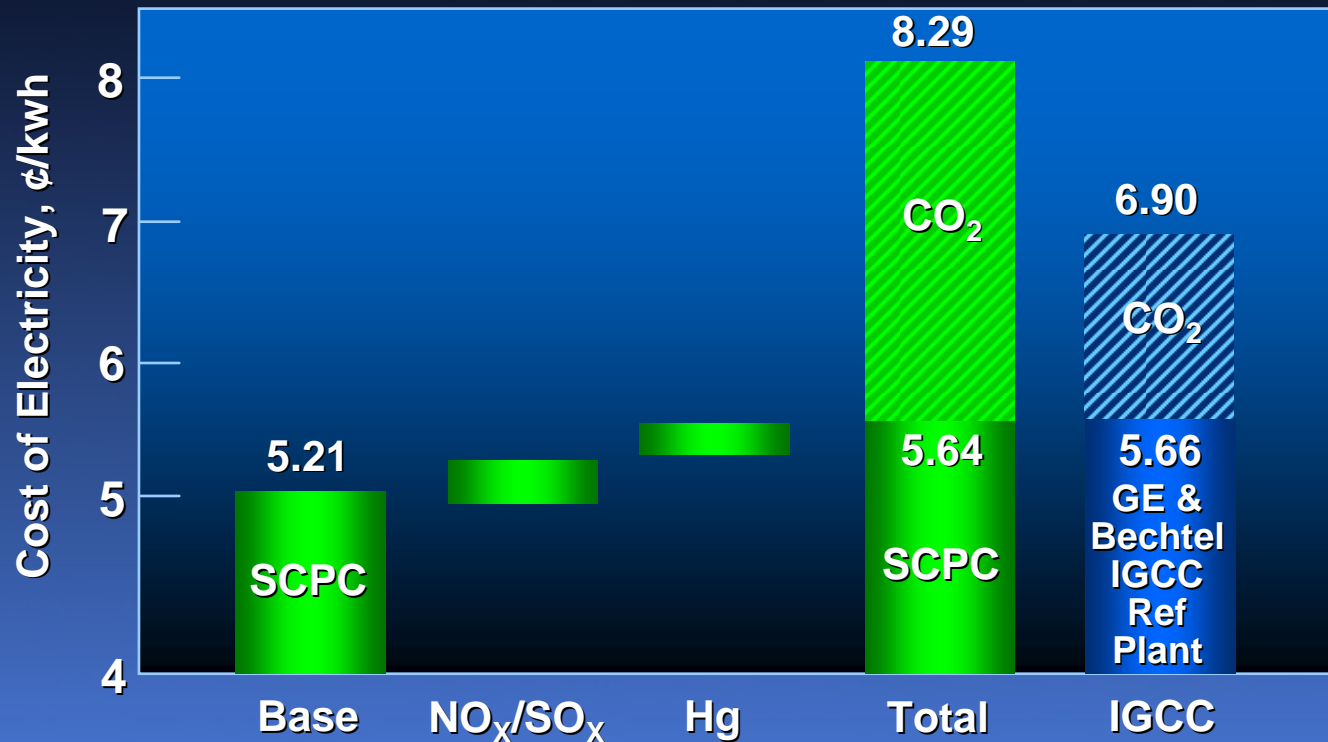
- Lignocellulosic biomass to fuels
- Algal oils to fuels

# Coal to Liquids

- **Coal is very cheap**
  - 0.5 to 2 \$/MMBtu
- **Coal is abundant**
  - 200 times as much as oil and gas
- **Syngas can be converted to liquids by Fischer Tropsch process**
  - 80% liquids yield
- **Gasification experience is growing**
- **Coal will play a big role in medium term**



# Gasification Economics



- Competitive with conventional coal-fired power generation when emissions control is included
- More innovation is needed to reduce cost for coal to liquids

Source: GE

# Summary

- **The oil industry is being challenged to provide cleaner fuels from worse feeds with soaring costs**
- **Integrating petrochemicals with refining can mitigate investment risk**
- **Integrating renewable fuels with refining - a viable option – technology is ready**
- **Heavy oil and coal technologies are improving**
- **Great opportunities for technology innovation!**



# Q & A