The New UOP SeparALL™ Process and UOP Polybed™ PSA
Honeywell’s Businesses

- **$37.6 billion** in revenues in 2012, 50% outside of U.S.
- Nearly **125,000** employees operating in 100 countries
- **19,000** engineers and scientists

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**Aerospace**

**Automation & Control Solutions**

**Performance Materials & Technologies**

**Transportation Systems**

Morristown, NJ global corporate headquarters
UOP Company Profile
Serving the Gas Processing, Refining & Petrochemical Industries

Profile — Significant Technology Position

Business Units:
- Gas Processing and Hydrogen (GP&H)
- Process Technology & Equipment (PT&E)
- Catalysts, Adsorbents & Specialties (CA&S)
- Renewable Energy and Chemicals (RE&C)

Offering:
- Technology, catalyst & services to the refining, petrochemical and gas processing industries
- Supplier of molecular sieve adsorbents to process and manufacturing industries

Sales: Breakdown

- Equipment: 45%
- Products: 35%
- Services: 13%
- Licensing: 7%

UOP Facilities — Global Footprint

Worldwide Headquarters
Des Plaines, Illinois (suburban Chicago)
3,500+ Employees

- 20 Offices
- 17 Countries
- 12 Manufacturing Facilities
- 5 Engineering Centers

Sales: Geographic

Global Customers

- North America: 32%
- Asia Pacific: 19%
- China: 12%
- Middle East: 9%
- South America: 9%
- E&A: 9%
- India: 5%
- CIS: 5%
Benefits of a UOP Integrated Solution in a Refinery

Our technologies and products are designed to deliver superior performance, safety and value when combined in an integrated system:

- High availability and reliability of processes and products
- Lower capital expenditure and operating costs resulting in lower cost of production of hydrogen
Hydrogen Dynamics in China

1. Critical feedstock for various industries
   - Refining industry
     - Hydrocracking, hydrotreating and isomerization processes
   - Ammonia Production
     - Approx. 0.18 – 0.20 kg hydrogen per kg of ammonia required

2. Environmental regulation / improved refinery performance
   - State Mandate – upgrade diesel and gasoline
   - Process heavier and more sour crude
   - Long on Heavy Fuel Oil (HFO) and Petroleum Coke
   - Improve margins by maximizing high-value refined product output

3. Demand for transportation fuels
   - Oil demand rising at >8% CAGR
   - Refining capacity to double from 2012 to 2022
   - China’s footprint expanding as a global supplier of refined products and fuels
Growth Potential for Hydrogen

Growth for hydrogen will mainly come from the oil refining industry.

Source: Chem1 Market Assessment Study for Hydrogen

Hydrogen segment assessment in China (Million tons)

- Methanol
- Refineries
- Ammonia

CAGR 2012-2022:
- 8% (2012-2022)
- 8% (2012-2022)
- 2% (2012-2022)

Years:
- 2008
- 2009
- 2010
- 2011
- 2012
- 2015
- 2020
- 2022

Million Tons:
- 0
- 5
- 10
- 15
- 20
- 25
- 30

Source: Chem1 Market Assessment Study for Hydrogen
Five Year Plan Target … Control Sulfur Emissions

<table>
<thead>
<tr>
<th>Fuel Standards</th>
<th>State II Current</th>
<th>State III 2013</th>
<th>State IV 2015</th>
<th>State V</th>
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<tbody>
<tr>
<td>GASOLINE</td>
<td></td>
<td>150</td>
<td>50</td>
<td>10</td>
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<tr>
<td>Sulfur, ppm</td>
<td>500</td>
<td>500</td>
<td>150</td>
<td>35</td>
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<tr>
<td>Olefin, v%</td>
<td>35</td>
<td>35</td>
<td>50</td>
<td>0.016</td>
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<tr>
<td>Manganese, g/L</td>
<td>74</td>
<td>72</td>
<td>28</td>
<td>0.016</td>
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<tr>
<td>Vapor pressure (Summer), kappa</td>
<td>74</td>
<td>72</td>
<td>28</td>
<td>0.016</td>
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<tr>
<td>DIESEL</td>
<td></td>
<td>350</td>
<td>50</td>
<td>10</td>
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<tr>
<td>Sulfur, ppm</td>
<td>500</td>
<td>500</td>
<td>350</td>
<td>49</td>
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<tr>
<td>Cetane number</td>
<td>49</td>
<td>49</td>
<td>51</td>
<td>810-850</td>
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<tr>
<td>Density, 20℃ kg/cm³</td>
<td>820-860</td>
<td>820-860</td>
<td>820-845</td>
<td>820-845</td>
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<tr>
<td>Fatty acid ester</td>
<td>/ /</td>
<td>0.5%v, 11%m</td>
<td>/ , 11%m</td>
<td>/ , 11%m</td>
</tr>
<tr>
<td>Heavy Aromatics</td>
<td></td>
<td>/ /</td>
<td>/ /</td>
<td>/ /</td>
</tr>
</tbody>
</table>

Comments

China relies heavily on the ME for most of its oil supplies which is sour

ME Crude Oil Specs: Current
API = 34
S (wt%) = 1.75

API = 33.9
S (wt%) = 1.84

Improving energy efficiency combined with reducing greenhouse gas emissions are key in the five year plan


Increasing sour crude processing and stricter sulfur controls requires added capacity for hydrogen production
Breakdown of Feedstock for Hydrogen Production

Hydrogen market assessment in China (Million tons)

- **others**
- **coal**
- **NG**
- **ROG**

Year: 2008-2022

*Source: Chem1 Market Assessment Study for Hydrogen*

Coal gaining prominence as an alternative cheaper feedstock
### Current Hydrogen Production Methods

**FEEDSTOCK**
- Natural gas / Off gas / LPG
- Coal / Refinery Bottoms
- Naphtha / HFO
- Coal
- Others (H₂O, methanol etc.)

**TECHNOLOGY**

#### SMR + PSA
- CH₄ + H₂O → CO + 3H₂
- CO + H₂O → CO₂ + H₂

#### Gasification
- CnHm+(n/2)O₂ = nCO+m/2 H₂
- CnHm+nH₂O=nCO + (n+m/2)H₂
- CO + H₂O → CO₂ + H₂

#### Electrolysis
- 2H₂O → 2H₂ + O₂
- CH₃OH → CO + 2H₂
- CO + H₂O → CO₂ + H₂

**TARGET H₂ USERS**

#### Refining
- Hydrocracker / Hydrotreating / Isomerization

#### Chemicals
- Methanol / Ammonia / Aromatic derivatives

#### Power
- Coal to liquids > DME / Gasoline

#### Others
- Electronics / Metallurgy / Fuel

*Lower cost feedstock improves product margins*
Case Study Comparing SMR & Gasification

1. Basis

- **Natural Gas Price:** $13/MMBtu (HHV = 22,400 Btu/lb) - based on LNG imports
- **Petcoke Price:** $1/MMBtu (HHV = 15,000 Btu/lb)
- **Coal Price:** $3.50/MMBtu (HHV = 12,000 Btu/lb)
- **Hydrogen required for refinery:** 100,000 Nm3/h

2. Configurations
Hydrogen Production Cost

Hydrogen production cost in China, $/Nm³

Cheaper feedstock cost directly influences the cost of hydrogen production

SENSITIVITY ANALYSIS FOR PETCOKE FEED

Capex $ MM

Feedstock $/MMBTU

1.01
1.67

SENSITIVITY ANALYSIS FOR NATURAL GAS FEED

Feedstock, $/MMBTU

11.89
14.11

Capex $MM
What is the UOP SeparALL Process?

Absorption / regeneration process for selective removal of $\text{H}_2\text{S}$, COS, & $\text{CO}_2$
- Uses a “next generation” physical solvent (SELEXOL™ MAX Solvent)
- Uses a typical solvent-extraction flow-scheme
- Loading directly proportional to partial pressure

Physical vs Chemical
Typical Gasification Application

High Pressure is advantageous
SELEXOL MAX Solvent Characteristics

- **SELEXOL MAX Solvent**: A physical solvent
  - Chemically similar and completely compatible with SELEXOL Solvent
  - Clear fluid that looks like tinted water

- Regenerated by changing pressure, temperature or applying a stripping gas

- Unique selectivity characteristics desirable for gasification syngas treating

Relative Solubility Data

<table>
<thead>
<tr>
<th>Compound</th>
<th>Solubility</th>
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<tbody>
<tr>
<td>H₂</td>
<td>~ 1</td>
</tr>
<tr>
<td>CO</td>
<td>~ 2.2</td>
</tr>
<tr>
<td>CO₂</td>
<td>~ 76</td>
</tr>
<tr>
<td>COS</td>
<td>~ 175</td>
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<tr>
<td>H₂S</td>
<td>~ 680</td>
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**SELEXOL MAX Solvent = Selective**
Two Basic Flow-schemes

**Sulfur removal only**
- Typically for power applications
- Can reduce treated gas any desired sulfur level
- One solvent absorber with solvent regeneration

**Sulfur removal with separate CO\(_2\) removal** (CCS or chemicals production)
- Typically for chemicals, SNG or coal to liquids applications
- Typically involves more stringent product specifications
- Integrated solvent absorbers and solvent regeneration
UOP SeparALL Process Advantages

- Mild chilling
- Simple flow schemes with few pieces of equipment
- Lower solvent losses
- Absorbs NH₃, HCN and other trace contaminants, without the need for additional equipment
- Removes metal carbonyls
  - Metal carbonyls in treated syngas decompose at gas turbine burners and potentially plate-out on the gas turbine blades
  - Metal carbonyl can also act as catalyst poisons for chemical applications

Through its improved efficiency and next generation technology, the SeparALL process can reduce capital expenditures by up to 10 percent and operating expenditures by more than 20 percent.
The UOP SeparALL process provides > 99% availability

Availability exceeds typical gasifier availability (typically 80 - 90%)

UOP training and services teams work with operators to help optimize and maintain the system at peak efficiency
Commercial Experience in Gasification
## OPTI Canada Plant

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
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<tbody>
<tr>
<td><strong>Start-Up</strong></td>
<td>2008</td>
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<tr>
<td><strong>Application</strong></td>
<td>H₂ Production &amp; Fuel Gas</td>
</tr>
<tr>
<td><strong>Production</strong></td>
<td>337,000 Nm³/h syngas</td>
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<tr>
<td><strong>AGRU Duty</strong></td>
<td>Sulfur</td>
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<tr>
<td><strong>Syngas Flow</strong></td>
<td>320 MMSCFD @ 550 psia</td>
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<td><strong>Feedstock</strong></td>
<td>Visbreaker Residue</td>
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**OPTI Canada Plant**

Canada
## Sarlux IGCC Complex Plant

<table>
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<tbody>
<tr>
<td>Start-Up</td>
<td>2000</td>
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<tr>
<td>Application</td>
<td>Power $H_2$ Production</td>
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<tr>
<td>Production</td>
<td>550 MW net / 40000 Nm³/h</td>
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<tr>
<td>AGRU Duty</td>
<td>Sulfur</td>
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<tr>
<td>Syngas Flow</td>
<td>404 MMSCFD @420 psia</td>
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<td>Feedstock</td>
<td>Visbreaker Residue</td>
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Sarroch, Sardinia, Italy
API Energia IGCC Complex Plant

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<tr>
<td>Start-Up</td>
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<td>Application</td>
<td>Power</td>
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<td>Production</td>
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<td>AGRU Duty</td>
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<td>Syngas Flow</td>
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<td>Feedstock</td>
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Falconara, Italy
### Coffeyville Resources Plant

<table>
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<th>Feature</th>
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<tbody>
<tr>
<td>Start-Up</td>
<td>2000</td>
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<tr>
<td>Application</td>
<td>Ammonia Urea</td>
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<tr>
<td>Production</td>
<td>21 T/h</td>
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<tr>
<td>AGRU Duty</td>
<td>Sulfur &amp; CO₂</td>
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<tr>
<td>Syngas Flow</td>
<td>151 MMSCFD @535 psia</td>
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<tr>
<td>Feedstock</td>
<td>Pet coke</td>
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</table>

**Coffeyville Resources Plant**

Coffeyville, Kansas
Block Flow Diagram | Coffeyville Resources

Air Separation Unit → Air → N₂ → Ammonia Synthesis

O₂ → Polybed PSA → High Purity H₂ → Raw H₂ → CO₂ Purification

Quench Gasification → Syngas Scrubbing → CO Shift & Gas Cooling → Tail Gas → SELEXOL 2-Stage

CO₂ → Purified CO₂ → UAN Plant → UAN Product

NH₃ Product

Petroleum Coke

Acid Gas

CO₂ Vent
Commercial Experience in Gasification

Coffeyville Resources
Gasification Ammonia Complex

SELEXOL Unit

POLYBED PSA Unit
H₂ Purification – Polybed PSA Systems

H₂ + Impurities
High Pressure

FEED GAS

PRODUCT
H₂ @ High Purity
High Pressure

TAIL GAS
Impurities (+H₂)
Low Pressure

H₂ Purity 99.9 - 99.9999%
H₂ Recovery 60 - 90%
H₂ Feed pressure 6 - 40 bar g
H₂ Product pressure 5 - 39 bar g
Components of a PSA Unit

1. Control System
2. Valve Skid
3. Vessels & Adsorbents
4. UOP Service & Support
PSA Technology - Delivered as Equipment

**Engineering & Services**
- Process
- Mechanical
- Instrumentation
- Control System
- Project Management
- Quality Control
- Adsorbent Loading Supervision
- Control Loop Testing
- Unit Start-up
- Installation Checkout
- Operator Training

**Equipment & Fabrication**
- Adsorber Vessels
- Surge Tank
- Valve Skid
- Instrumentation & Valves
- Adsorbent
- Control System
PSA with Maximum On-Stream Reliability

For a customer in China that needs a reliable source of high purity hydrogen, UOP Polybed™ PSA provides greater than 99.8% on-stream availability that results in $500,000/day of additional value due to downtime avoided versus local PSA suppliers. We do this by providing proven designs, proprietary adsorbents, and equipment.

Assumptions:

• 100,000 Nm³/hour product PSA unit
• H₂ value = 15000 RMB/MT = $0.21/Nm³
• Calculation: 100,000 x 24 x 0.21 = $504,000/day
• The cost from the loss of production from the downstream hydroprocessing units, if known, would be added to the cost of the loss of H₂
Q&A

Question and Answer