Advanced Techniques for Enhancing Hydrogen Availability in Refineries

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Air Products and Chemicals
Presentation Overview

• Global Hydrogen (H₂) demand projections
• Ways to enhance H₂ Availability
  – Advanced Hydrogen Management
  – Step capacity Revamping & Feed switching to NG
  – Mega H₂ concept
  – Make v/s Buy
  – Reliability Enhancement
• Conclusions
Presentation Overview

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• Conclusions
Drivers for Refinery Hydrogen

- Volume growth
  - Global fuels demand growth + clean fuels catch-up
  - Increasing proportions of ‘Opportunity and/or Unconventional’ crudes
  - Bottom-of-the barrel strategies
- Economies of scale
- Multi-client hydrogen franchise networks
- Hydrogen considered as an asset in refinery
  - Optimization and not minimization of hydrogen usage
  - Focus on ‘operating margins’ rather than ‘operating costs’

Mega H₂ plant typically ranges 100 - 250 kNm³/h in a single train
“Refinery Hy-way” Intensification

- Oil-gas price gap
- Opportunity Crudes
- Dieselization
- BoB upgrading; Min. FO
- Clean Fuels
- Heavy/Sour Crude
- More Hydrogen !!

H₂ Demand

Time-line

2000

2012
# Global Refinery Hydrogen Demand Growth

<table>
<thead>
<tr>
<th>Year</th>
<th>2001</th>
<th>2011</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global H2 Demand, (Captive; On-purpose)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCFD</td>
<td>12.8</td>
<td>18.5</td>
<td>26.5</td>
</tr>
<tr>
<td>North America:</td>
<td>4.7</td>
<td>5.8</td>
<td>7.1</td>
</tr>
<tr>
<td>Western Europe</td>
<td>3.1</td>
<td>3.2</td>
<td>3.7</td>
</tr>
<tr>
<td>Asia/Pacific:</td>
<td>3.0</td>
<td>5.7</td>
<td>9.6</td>
</tr>
<tr>
<td>- China</td>
<td>0.6</td>
<td>1.8</td>
<td>3.7</td>
</tr>
<tr>
<td>- India</td>
<td>0.3</td>
<td>0.9</td>
<td>1.7</td>
</tr>
<tr>
<td>- Japan</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>- Other Asia/Pacific</td>
<td>1.1</td>
<td>2.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Other Regions (SA, ME, AFR)</td>
<td>2.0</td>
<td>3.8</td>
<td>6.1</td>
</tr>
<tr>
<td>% growth (2011 – 2021) Global</td>
<td>~4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India + China</td>
<td>~7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global H₂ growth (2011-2021): Captive + 20% Merchant</td>
<td>10 bcfd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average bcfd/yr</td>
<td>~1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Refinery Hydrogen: Asian Trends & Needs

• Technical
  – Larger plant capacities
  – Catch-up against US & Euro norms
  – Lack of NG: Multiple / Liquid feedstocks flexibility
  – Power (un)reliability
  – Increasing HSE requirements and CO₂ focus
  – Need for enhanced RAM (Reliability, Availability and Maintenance)

• Commercial
  – Higher demand growth v/s domestic crude scarcity
  – Product slate and demand pattern; Diesel v/s Gasoline
  – Lower cost of ownership for H₂ critical for refinery profitability
  – Larger domestic portion in execution of projects (materials and labour)
Technip Catering for Hydrogen Demand

- Custom-optimized Solutions
- State-of-the-art technology

Over 260 Plants

Leading Global Hydrogen Technology and Plant Supplier

Global Market Share
Presentation Overview

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• Conclusions
Refinery Off Gas (ROG) H₂ Recovery and Utilization

Refinery Off Gases (ROG)

End users - A
High Purity H₂ Recovery

End users - B
Low Purity H₂ Recovery
Blending

Compression / pre-treatment

End users - C
Compression

Purity and Pressure Cascading

Hydrogen Plant

HC feedstock

High Purity Hydrogen Network

Refinery Fuel Gas Network
Advanced Hydrogen Management

• Specific methodologies combined with transversal competences
  – Advanced LP programming using PIMS platform
  – Suite of tools includes H₂-pinich analysis and purity / pressure cascading
  – Rigorous unit operation modelling simulator, data import and reconciliation
  – Global cost database for realistic economic analysis and case evaluation

• Tailored to specific objective functions for grassroots refineries as well as revamps, expansions & retrofits of existing refineries

• No compromise on safety, reliability and operational flexibility
## HyN-DT Analysis Cluster Output

### Hydrogen Balance

<table>
<thead>
<tr>
<th>Users</th>
<th>Mass Rate (t/d)</th>
<th>Nm³/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2 for Naphtha HDT</td>
<td>6.39</td>
<td>2983</td>
</tr>
<tr>
<td>H2 for Kero HDS</td>
<td>2.25</td>
<td>1052</td>
</tr>
<tr>
<td>H2 for Diesel HDS</td>
<td>17.12</td>
<td>7994</td>
</tr>
<tr>
<td>H2 for Hydrocracker</td>
<td>508.22</td>
<td>237297</td>
</tr>
<tr>
<td>H2 for ARO Complex</td>
<td>17.00</td>
<td>7936</td>
</tr>
<tr>
<td><strong>Tot</strong></td>
<td><strong>551.0 t/d</strong></td>
<td><strong>257264 Nm³/h</strong></td>
</tr>
</tbody>
</table>

### Syngas Distribution

<table>
<thead>
<tr>
<th>Sweet Syngas Distribution</th>
<th>T/Day</th>
<th>Default Split</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet Syngas to Power</td>
<td>2943.0 t/d</td>
<td>52.65</td>
</tr>
<tr>
<td>Sweet Syngas to Hydrogen</td>
<td>2646.3 t/d</td>
<td>47.35</td>
</tr>
<tr>
<td>Sweet Syngas to Fuels</td>
<td>0.0 t/d</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Tot</strong></td>
<td>5589.3 t/d</td>
<td>100.00</td>
</tr>
</tbody>
</table>

### Refinery Fuels Balance

<table>
<thead>
<tr>
<th>Hydrogen Unbalance</th>
<th>0.0 t/d</th>
<th>0.0 Nm³/h</th>
</tr>
</thead>
</table>

(+-, shortages/overproduction)

STOP BLINK

**Naphtha Warning**

**NO SHORTAGE**

### Refinery Energy Balance

<table>
<thead>
<tr>
<th>Refinery Fuels Availability</th>
<th>MMKcal/h</th>
<th>503.24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery Fuels Demand</td>
<td>MMKcal/h</td>
<td>755.84</td>
</tr>
<tr>
<td>Delta (+import/-excess)</td>
<td>MMKcal/h</td>
<td>252.60</td>
</tr>
</tbody>
</table>

### Fuels Import

<table>
<thead>
<tr>
<th>Fuels</th>
<th>LHY</th>
<th>Kcal/Kg</th>
<th>T/Day</th>
<th>MMKcal/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td></td>
<td>11700.00</td>
<td>518.16 t/d</td>
<td>252.60</td>
</tr>
<tr>
<td>Fuel Oil M 100</td>
<td></td>
<td>10680.00</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### Fuels Export

<table>
<thead>
<tr>
<th>Fuels</th>
<th>LHY</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery Fuel gas (flare)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12464.55</td>
<td>0.00 t/d</td>
</tr>
<tr>
<td>Fuel Oil M 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10680.00</td>
<td>0.00 t/d</td>
</tr>
</tbody>
</table>
**HyN•DT™ Example Analysis : Base Case**

- **NAPHTHA HDT HP Separator**
  - 24.1 Barg
  - 6.4 t/d
  - 67.8% vol.

- **KEROSENE HDT HP Separator**
  - 24.3 Barg
  - 0.2 t/d
  - 16.1% vol.

- **DIESEL HDT HP Separator**
  - 58 Barg
  - 1.0 t/d
  - 33.9% vol.

- **HYDROCRACKER HP Separator**
  - 155 Barg
  - 8.0 t/d
  - 81.5% vol.

- **Fractionator**
  - Cold Sep.
  - 45.2 t/d
  - 90.6% vol.

- **RFG Network**
  - Cont. H2
  - 108.2 t/d

- **H2 High Purity Network, 99.9% vol.**

- **NEW HGU PSA**
  - (H2)
  - 73,352 Nm³/h
  - 157.1 t/d

- **CCR PSA**
  - (H2)
  - 70,937 Nm³/h
  - 151.9 t/d

- **AROMATICS COMPLEX**
  - ISOMAR TATORAY
  - 13.1 t/d

- **Existing HGU PSA**
  - (H2)
  - 112,977 Nm³/h
  - 242.0 t/d

- **FG Network**
  - 11.3 t/d
  - 58.7% vol.

- **Cont. H2**
  - 257,264 Nm³/h
  - 551 t/d

- **HyN•DT Example Analysis : Base Case**
HyN\textsuperscript{DT} Analysis: Optimized Select Case

**FG Network**

- NAPHTHA HDT HP Separator 24.1 Barg
- KEROSENE HDT HP Separator 24.3 Barg
- DIESEL HDT HP Separator 58 Barg
- HYDROCRACKER HP Separator 155 Barg

**H2 High Purity Network, 99.9\% vol**

- 12,046 Nm3/h 26 t/d
- 6.4 t/d 67.8\% vol.
- 2.3 t/d 16.1\% vol.
- 17.1 t/d 10.1\% vol.

**H2 Low Purity Network, 90 \% vol**

- 508.2 t/d
- 38.9 t/d
- 25.8 t/d

**NEW HGU (H2)**

- 43,143 Nm3/h
- 92.4 t/d
- 151.9 t/d

**EXISTING HGU (H2)**

- 112,977 Nm3/h
- 33.1 t/d 53.3\% vol.

**AROMATIC COMPLEX**

- GCR (H2) 70,937 Nm3/h
- 3.9 t/d
- 13.1 t/d 242.0 t/d

**PSA**

- 245,212 Nm3/h 525 t/d

**Cont.H2**

- 37 t/d

**H2 Low Purity Network**

- 7.3 t/d

**~ 40% reduction**

**FG Network**

- 11.3 t/d 58.7\% vol.

**HGU (H2)**

- 1,0 t/d 81.5\% vol.
- 8.0 t/d 81.5\% vol.

**RFG Network**

- 6.3 t/d 57.6\% vol.
- 3.1 t/d 67.8\% vol.
- 0.2 t/d 16.1\% vol.

**PSA**

- 43,143 Nm3/h
- 112,977 Nm3/h
- 70,937 Nm3/h
- 43,143 Nm3/h

**HyN•DT\textsuperscript{TM}**
Refinery Off gases (ROG) Integration

Qualifiers
- Available pressure
- Contaminants

Potential H₂ Contribution (Quantity * H₂ fraction)

Low, Medium, High
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- Conclusions
Hydrogen Step Capacity Revamp

• Benefits
  – Lower unit cost of (additional) hydrogen
  – Shorter schedule
  – No or smaller additional plot space
  – Utility interfaces and staff in place

• Process Options
  – Pre-reformer integration (up to 10%)
  – Reformer upgrade (up to 15%)
  – TPR reformer retrofit (up to 30%)

Attractive additional Hydrogen with
No compromise on HSE and Reliability
Technip Parallel Reformer (TPR) Retrofit

- Uses high grade heat of reformer effluent to reform additional feed
- More reforming without increasing radiant duty, thus lowering firing and related CO₂ per unit H₂
- Off-loads the whole steam system despite higher capacity
- Allows near ‘Zero’ export steam
- Installation within a typical refinery turnaround (4-6 weeks)
TPR Regenerative Reforming Cycle

- Up to 30% more H₂
- Lower Export Steam
- Lower corrected Specific CO₂ Emission
## Recent TPR Revamps Overview

<table>
<thead>
<tr>
<th></th>
<th>Project 1</th>
<th>Project 2</th>
<th>Project 3</th>
<th>Project 4</th>
<th>Project 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-revamp capacity (kNm3/h)</td>
<td>13.5</td>
<td>34</td>
<td>16.5</td>
<td>38</td>
<td>96</td>
</tr>
<tr>
<td>Incremental capacity (kNm3/h)</td>
<td>3.4</td>
<td>9</td>
<td>5</td>
<td>9</td>
<td>21</td>
</tr>
<tr>
<td>Capacity increase (%)</td>
<td>25</td>
<td>26</td>
<td>30</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>Feedstock</td>
<td>Naphtha/ NG</td>
<td>Naphtha</td>
<td>NG</td>
<td>NG</td>
<td>NG</td>
</tr>
</tbody>
</table>
Feed Switching (from Naphtha) to NG

• Expanding NG networks
• Higher H2 yield due and improved process efficiency
• NG feed Opex generally lower than for Naphtha, when latter credits higher premium as Petrochemicals feedstock
• Reduced CO₂ emission (~ 15%)
• Easier to operate (even more with fuel substitution)
  – No residue on evaporation / fouling
  – Easier desulphurization
  – No liquid pockets or slugs, esp during transient conditions
  – Reduced risk on carbon formation in SMR even with lower S/C
  – More stable composition and quality
  – Easier to recover from upsets
• On-line feed change-over well referenced (as alternative and/or mixed feed)
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Hydrogen Generation: Economy of Scale

Basis: Natural Gas @ € 20/Gcal

Capex + Opex

7% variation in Relative UCH

H2 Plant Capacity, kNm3/h

Relative UCH, %
Benefits of Single v/s Dual Train H₂ Plant

- Total Installed Cost lowered by 10-15%
- Smaller plot space by 30-50%
- Enhanced energy efficiencies, apart from better justification for incremental investment
- Shorter implementation schedule and/or labor intensity
- Lower operating costs (staff, inventories and capital spares)
- More suitable for CO₂ capture readiness

- Such merits outweigh the minor benefit on lower turn-down and plant availability of Dual-train units, with negligible impact on overall on-stream factor.
- Dual train configuration at times gets governed by phased investment and execution philosophy or case-specific requirements
- Large single-train H₂ plants do call for a higher degree of design optimization and competence as well as EPC capabilities and experience.
Mega Hydrogen Plants with Feed Flexibility
• Global Hydrogen (H₂) demand projections

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# Hydrogen supply: Make v/s Buy

<table>
<thead>
<tr>
<th></th>
<th>Make Case</th>
<th>Buy Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key design objective</td>
<td>Low capital cost</td>
<td>Optimized UCH</td>
</tr>
<tr>
<td>Financing &amp; insurance</td>
<td>Customer</td>
<td>Supplier</td>
</tr>
<tr>
<td>Project / construction risk</td>
<td>Customer / Contractor</td>
<td>Supplier</td>
</tr>
<tr>
<td>Permitting &amp; commissioning</td>
<td>Customer</td>
<td>Supplier</td>
</tr>
<tr>
<td>Warranty</td>
<td>Typically 1 yr after ‘start up’</td>
<td>20 years</td>
</tr>
<tr>
<td>Performance guarantee</td>
<td>GTR within 2-12 months</td>
<td>20 years</td>
</tr>
<tr>
<td>On-stream guarantee</td>
<td>None</td>
<td>20 years</td>
</tr>
<tr>
<td>Opex liabilities</td>
<td>None</td>
<td>20 years</td>
</tr>
<tr>
<td>Major failure after warranty</td>
<td>None</td>
<td>20 years</td>
</tr>
</tbody>
</table>
Air Products- Technip Global H₂ Alliance

• Incepted in 1992
• Befitting Synergy
  – Technip’s leadership in H₂ plant supply
  – Air Products’ leadership in OTF H₂ supply
• 34 plants to date
  > 2.5 bcfd H₂ capacity
  > 1 bcfd H₂ in past 5 years

Longest and most successful Sale-of-Gas H₂ alliance
GTE - SMR Cogen Integration / Combined Cycle

- **Gas Turbo Generator**
- **Process Steam**
- **Export Steam**
- **Steam Turbo Generator**
- **Steam Drum**
- **HRSG**
- **Aux. firing (Optional)**
- **Boiler**
- **Economizer**
- **To Stack**
- **To PG Boiler**

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*HYDROCARBON PROCESSING 2013*

NEW DELHI, INDIA | 9-11 JULY
Benefits of SMR / Cogen Integration

- Better Economics compared to stand-alone units
  - Lower TIC by ~ 10%
  - O & M staffing synergies benefit ~ 5%
  - Improved thermal efficiency benefit ~ 3%
- Reduced specific CO₂ and NOx by ~ 15%
- Island mode capabilities during special operational modes
  - Enhanced reliability for H₂ (>99.9%) as well as power supply for the refinery complex under various H₂ / power load ratios
- Upto 100 MW generation from 100 mmscfH₂ plant
- Reliable and cost-effective (captive) power self-sufficiency
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Air Products-Technip Reliability Program

- Reliability Focused Operations and Work Processes
  - Global Downtime and Cost of Non-conformance (CoNC) metrics
  - Advanced Model Predictive Control (MPC) control strategies
  - State of the art Condition Monitoring (CM)
  - Standardized outage planning and execution
  - Critical Spares management
  - Robust Electronic Management of Change (MOC) system
  - Best Practices sharing amongst sites worldwide
  - Extensive use of Continuous Improvement Tools
  - Site Reliability, Training, and Procedure Assessment Programs in place
Refinery H₂ underlines strong need for high reliability and availability

<table>
<thead>
<tr>
<th>Start-up Year</th>
<th>Capacity MMSCFD</th>
<th>% On-stream *</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>35</td>
<td>99.1</td>
</tr>
<tr>
<td>1995</td>
<td>88</td>
<td>99.3</td>
</tr>
<tr>
<td>1996</td>
<td>80</td>
<td>99.1</td>
</tr>
<tr>
<td>1997</td>
<td>17.5</td>
<td>99.2</td>
</tr>
<tr>
<td>2000</td>
<td>96</td>
<td>99.6</td>
</tr>
<tr>
<td>2002</td>
<td>100</td>
<td>99.9</td>
</tr>
<tr>
<td>2004</td>
<td>110</td>
<td>99.8</td>
</tr>
<tr>
<td>2006</td>
<td>82</td>
<td>99.9</td>
</tr>
<tr>
<td>2007</td>
<td>115</td>
<td>99.9+</td>
</tr>
<tr>
<td>2008</td>
<td>105</td>
<td>99.9+</td>
</tr>
<tr>
<td>2011</td>
<td>120</td>
<td>100.0 to date</td>
</tr>
</tbody>
</table>

* Based on documented reliability data of AP-TP SOG H₂ plants, excluding scheduled outage
## Progression of “Cost-Effective Reliability”

<table>
<thead>
<tr>
<th>Feature</th>
<th>Early 90s</th>
<th>Mid 90s</th>
<th>2005 +</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single (SMR) train max. H₂ capacity, mmscfd</td>
<td>75</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Relative Reformer box size (m x m x m), %</td>
<td>100</td>
<td>85</td>
<td>75</td>
</tr>
<tr>
<td>Relative Specific energy (GJ/kNm³), %</td>
<td>100</td>
<td>94</td>
<td>90</td>
</tr>
<tr>
<td>Relative Burner-NOx target (ppmV), %</td>
<td>100</td>
<td>65</td>
<td>30</td>
</tr>
<tr>
<td>Continuous operation / turnaround cycle, years</td>
<td>~ 2</td>
<td>~ 3</td>
<td>~ 4</td>
</tr>
<tr>
<td>Reliability (stand-alone on-stream), %</td>
<td>&gt; 95 %</td>
<td>&gt; 97 %</td>
<td>&gt; 99 %</td>
</tr>
<tr>
<td>Relative Plot area ISBL (m x m), %</td>
<td>100</td>
<td>90</td>
<td>75</td>
</tr>
<tr>
<td>Relative EPC execution schedule (months), %</td>
<td>100</td>
<td>90</td>
<td>80</td>
</tr>
<tr>
<td>Relative TIC (ISBL; adjusted NPV; MM $), %</td>
<td>100</td>
<td>95</td>
<td>85</td>
</tr>
<tr>
<td>Relative ‘Unit Cost of Hydrogen’ ($/kNm³), %</td>
<td>100 %</td>
<td>94 %</td>
<td>88 %</td>
</tr>
</tbody>
</table>
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• Global Hydrogen (H$_2$) demand projections
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• Conclusions
Conclusions

- The growing refining landscape and its emerging needs, especially in Asia, call for concerted strategies for ensuring H₂ availability efficiently and cost-effectively.

- In modern high-conversion integrated refineries, H₂ need can be satisfied starting with judicious hydrogen management, followed by potential capacity revamp of existing H₂ plants, and eventually efficient & reliable H₂ generation, furthered by ‘buy’ mode via over-the-fence supply.

- Asian refining and hydrogen markets carry few specific trends and needs to be addressed for meeting the ongoing and future goals.

- Technip as a global leader for supply of H₂ technology and plants, together with its trend-setting global alliance with Air Products, carries a comprehensive portfolio of proven technological options and advanced solutions for satisfying current and upcoming H₂ needs.
Thank You!

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