Use and Optimization of Hydrogen at Oil Refineries

DOE H2@Scale Workshop – University of Houston
May 23, 2017

Aimee LaFleur
Process Engineer
Shell Innovation, Research & Development – Downstream Technology
Definitions & cautionary note

Reserves: Our use of the term "reserves" in this presentation means SEC proved oil and gas reserves.

Resources: Our use of the term "resources" in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers (SPE) 2P + 2C definitions.

Discovered and prospective resources: Our use of the term "discovered and prospective resources" are consistent with SPE 2P + 2C + 2U definitions.

Organic: Our use of the term Organic includes SEC proved oil and gas reserves excluding changes resulting from acquisitions, divestments and year-average pricing impact.

Shales: Our use of the term 'shales' refers to tight, shale and coal bed methane oil and gas acreage.

Underlying operating cost is defined as operating cost less identified items. A reconciliation can be found in the quarterly results announcement.

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate legal entities. In this presentation “Shell”, “Shell group” and “Royal Dutch Shell” are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words “we”, “us” and “our” are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. “Subsidiaries”, “Shell subsidiaries” and “Shell companies” as used in this presentation refer to companies over which Royal Dutch Shell plc either directly or indirectly has control. Entities and unincorporated arrangements over which Shell has joint control are generally referred to as “joint ventures” and “joint operations” respectively. Entities over which Shell has significant influence but neither control nor joint control are referred to as “associates”. The term “Shell interest” is used for convenience to indicate the direct and/or indirect ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

This presentation contains forward-looking statements concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management’s current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management’s expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as “anticipate”, “believe”, “could”, “estimate”, “expect”, “goods”, “intend”, “may”, “objectives”, “outlook”, “plan”, “probably”, “project”, “risks”, “schedule”, “seek”, “should”, “target”, “will” and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this presentation, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell’s products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; and (m) changes in trading conditions. No assurance is provided that future dividend payments will match or exceed previous dividend payments. All forward-looking statements contained in this presentation are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell’s Form 20-F for the year ended December 31, 2016 (available at www.shell.com/investor and www.sec.gov). These risk factors also expressly qualify all forward-looking statements contained in this presentation and should be considered by the reader. Each forward-looking statement speaks only as of the date of this presentation, May 23, 2017. Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or announce any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this presentation.

We may have used certain terms, such as resources, in this presentation that United States Securities and Exchange Commission (SEC) strictly prohibits us from including in our filings with the SEC. U.S. investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website www.sec.gov. You can also obtain this form from the SEC by calling 1-800-SEC-0330.
Agenda

Refinery Configurations and H₂ Demand
H₂ Sources
H₂ System Management
Steam Methane Reformer as the Industry Standard
H₂@Scale – Framing the Opportunity
Refinery Technology Development Goals
Refinery Configurations Dictate H₂ Demand

- Simple → Complex Refineries
  - Existing infrastructure investment and modifications are site specific
- Role of Hydrogen – Hydroprocessing
  - Hydrotreating - to remove impurities (sulfur), hydrogenate aromatics and olefins
  - Hydrocracking – Break larger molecules into smaller, higher value molecules
- Hydrogen demand
  - Depends on configuration and feedstock quality (sulfur content)
Utilize Internal H₂ Production, then Import

**Primary Source**
H₂ byproduct of primary gasoline production

**Heavy Oil Management Refinery Configuration**

- **Catalytic Reformer**
- **Steam Methane Reformer**
- **Gasification/Partial Oxidation of Oil**
- **Steam Cracker Tail Gas Recovery**

**3rd Party Import**
Managed with Supply Contracts with IGC’s either as dedicated plant supply or via industrial pipeline network

- Referred to as H₂ Manufacturing Unit (HMU), Bulk H₂ Production
- Refinery and Chemical Plant Integration
Hydrogen System Management - Optimization

- **Steam Methane Reformer**
  - Primary H₂ Producer (99.9% Purity)
  - High P Steam Byproduct
  - 360 psig (25 bar)

- **Catalytic Reformer**
  - Reforms Naphtha to Reformate for Gasoline Blending
  - H₂ Byproduct (75% Purity), can be purified with PSA (99.9%) or AGR (97%)
  - CCR - 50 psig (3 bar)
  - SCR - 220-430 psig (15-30 bar)

- **Hydrocracker**
  - 2000 psig (140 bar)
  - Vent (60-85% Purity)

- **Diesel Hydrotreater**
  - 220 – 725 psig (15-50 bar)

- **Kero Hydrotreater**
  - 99.9 Purity
  - Vent (65-80% Purity)

- **Naphtha Hydrotreater**
  - Vent (65-80% Purity)

- **Membrane**
  - 90+% Purity
  - Reformer Vent (70-90% Purity)

**FUEL SYSTEM**

May 2017

Copyright of Shell International
Steam Methane Reforming – The Industry Standard

Steam Methane Reformer (SMR)

- Natural Gas
- Steam
- Fuel

Water Gas Shift

- Flue Gas
- HPS Export
- CO/CO₂

Pressure Swing Adsorption (PSA)

- Raw H₂
- 99.9% H₂

Low Cost
- High efficiency, turn-key installation
- Steam Export

High Purity
- Integrated PSA Technology offers very high purity
- Reliability
- High pressure steam export for integration with refinery
- Steady operation, 3rd party supply network

Copyright of Shell International

May 2017
Framing the Opportunity

**H₂@Scale Opportunity**
Replace SMR based H₂ volumes at refineries. This can potentially include H₂ firing of assets.

**Competitiveness**
Understanding green hydrogen technology competitiveness and timing with SMR + CCS.

**Timing for Investment**
Market headed towards tighter sulfur specifications, resulting in increased hydrogen demand. Replacing an aging infrastructure.

**The Near Term CO₂ Challenge**
Driving towards decarbonisation within existing infrastructure through targeting energy efficiency, pre-combustion, and post-combustion capture opportunities.

**Collaboration**
Partnering with H₂ suppliers to optimize cost for refineries helping maintain refinery margins.
Refinery Technology Development Goals

What does a mature hydrogen economy look like for the refinery?

- Manage $H_2$ purity and cost within the system
  - (Refinery vs. Mobility vs. Other end use)

- Maintain scale, integration, reliability and purity based on SMR standard

- Maximize potential new, integration opportunities i.e. electricity, steam, etc.
Questions and Answers