Oil Refining in a CO\textsubscript{2} Constrained World
Implications for Gasoline & Diesel Fuels

Amir F.N. Abdul-Manan & Hassan Babiker
Strategic Transport Analysis Team (STAT),
Saudi Aramco
Agenda

1. **Global Mobility Dynamics** - Why was this study done?
2. **Methodology** - How was it done?
3. **Results** - What did we find?
4. **Implications** - So what?
5. **Final Thoughts** - Where do we go from here?
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Global Mobility Dynamics

**Demand Lock-In**

- Demand driven by Non-OECD Countries
- Mobility Drives Demand for Oil
- Oil Enables Mobility

**More than 50% of Oil Ends Up in Transport Sector**

- Residential/Commercial 7%
- Transportation 55%
- Industrial 32%
- Power Generation 6%

- Oil 33%
- Gas 22%
- Coal 27%
- Nuclear 5%
- Biomass/Waste 9%
- Hydro 2%
- Other Renewables 2%

*Data Source: Exxon Mobil 2016 Energy Outlook*
Global Mobility Dynamics

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Transport Will Continue to be More than 85% Reliant on Oil

% Oil Share of Transport Energy

Data Sources:
1) Exxon Mobil 2016 Energy Outlook
2) BP 2016 Energy Outlook
3) IEA 2016 International Energy Outlook
Global Mobility Dynamics

**Policy Interventions**

- Renewable Fuels Mandate.
- Fuel Economy Standards
- GHG Emissions Control.
- Criteria Air Pollutants Control

**Increasingly Stringent Fuel Economy Standards Worldwide**

*Data Sources: ICCT (http://www.theicct.org/blogs/staff/improving-conversions-between-passenger-vehicle-efficiency-standards)*
Global Mobility Dynamics

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Obligatory Biofuels Blending Requirements Worldwide

Data Sources: WBCSD 2015 “Low Carbon Technology Partnerships Initiative”
Global Mobility Dynamics

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**Government Inducements for Transport Electrification**

*Figure 1* - Evolution of the global electric car stock, 2010-15

Note: the EV stock shown here is primarily estimated on the basis of cumulative sales since 2005.

Global Mobility Dynamics

**Policy Interventions**

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**IMO’s New Low Sulphur Limit for Marine Fuels**

**Demand for Global Marine Fuels with 2020 Full Enforcement Scenario**

- Distillate
- HSFO
- LSFO
- ULSFO
- LNG

Data Sources: WoodMackenzie
Global Mobility Dynamics

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Implication: Demand Disparity for Refined Products

Global transportation demand by fuel (MBDOE)

Data Source: Exxon Mobil 2016 Energy Outlook
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**Implication: Demand Disparity for Refined Products**

![Historical Global Energy Consumption Trend](image)

*Data Source: EIA 2016 (International Energy Statistics - Beta)*

![Projected Product Demand Skew](image)

*Data Source: OPEC 2015*
Global Mobility Dynamics

What are the Intrinsic Refinery CO₂ Values of Diesel & Gasoline Fuels in a World that is Constrained on CO₂?
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Methodology - 6 Regional Refining Systems...

Refinery LP Models

- 6 regions globally:
  - North America
  - South America
  - Europe
  - Middle East
  - Asia (excl. China)
  - China

- Calibrated against 2014 actual estimates by IHS Consultancy.

- ~ 98% of 2014 global refinery throughputs.
Methodology - 2 Scenarios & 9 Pricing Levels

Scenario 1: 2014 Estimate

“How will refineries meet today’s products demands under different CO₂ pricing incentives?”

- Product demands fixed at 2014 production levels and based on existing capacities in 2014.
- CO₂ price varied:
  - 0 - 500 $/t CO₂

Scenario 2: Optimised

“What is the optimal production for refineries under different CO₂ pricing incentives?”

- Optimal production levels based on existing refinery capacities in 2014.
- CO₂ price varied:
  - 0 - 500 $/t CO₂
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Results - Overview of Regional Refining Systems

CO₂ Emissions Sources & Efficiency - Base Case

Refinery CO₂ Emissions (Scope 1 + 2)

CO₂ Emissions Breakdown (% wt)

<table>
<thead>
<tr>
<th>Region</th>
<th>Catalytic Cracking (FCC &amp; RFCC)</th>
<th>H₂ Plant</th>
<th>Refinery Fuel</th>
<th>Utility Generation</th>
<th>Refining Systems Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia (excl. China)</td>
<td>20%</td>
<td>20%</td>
<td>40%</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>China</td>
<td>20%</td>
<td>20%</td>
<td>40%</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>Europe + CIS</td>
<td>20%</td>
<td>20%</td>
<td>40%</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>Middle East</td>
<td>20%</td>
<td>20%</td>
<td>40%</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>North America</td>
<td>20%</td>
<td>20%</td>
<td>40%</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>South America</td>
<td>20%</td>
<td>20%</td>
<td>40%</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>Global Average</td>
<td>20%</td>
<td>20%</td>
<td>40%</td>
<td>20%</td>
<td>100%</td>
</tr>
</tbody>
</table>

LHV-based Refining System Efficiency (%)
Results - Overview of Regional Refining Systems
Carbon Intensity of Gasoline & Diesel Fuels - Well-to-Tank (WtT)

Gasoline is more Carbon Intensive to Produce than Diesel

Well Accepted Conclusion within Industry & Policymakers
Results - Effects of Carbon Pricing
Implications for Efficiency and Emissions

What is the most profitable may not necessarily be the most efficient.

Pricing levels that begin to affect refinery decisions

Only complex refineries (such as in the US) can sustain productions under a very high CO₂ price without passing on the cost to consumers.
Results - Effects of Carbon Pricing
Impacts on Operations & Profitability

Global Refined Products

Share of regional refinery productions (% energy)

Carbon Price ($/ton)

% total refined products globally over 2014 demand

Asia
Europe
North America
China
Middle East
South America

% Global Production over 2014 Demand
Results - Re-optimizing Production Mix for Lower Refinery CO2

- Faster drop in diesel production starts to be impacted at ~$50/ton of CO2.
- Production of gasoline and diesel can still meet 2014 market demand up to ~ $100/ton CO2.
- Production of diesel drops at a much faster rate than gasoline, reversing the trend in (D+J)/G ratio shift.
Results - Re-optimizing Gasoline/Diesel Production Ratio

Refinery shifts towards cleaner hydrogen source

Refinery Hydrogen Balance

- **Reformer**
- **Hydrogen Plant**
- **Total H2 Requirements - Normalised**

Drop diesel production:

→ Reduce demand for hydrogen

→ Shift to a Cleaner H2 Source for the Refinery
**Results** - Marginal CO₂ Values of Gasoline & Diesel. Diesel Worse than Gasoline - Contrary to Popular Studies

### Regulatory Approach
- **gCO₂eq/MJ**
  - **Gasoline**
    - GREET 2014: 20.6
    - EPA RFS 2: 17.0
  - **Diesel**
    - GREET 2014: 18.2
    - EPA RFS 2: 17.1

### Directional Change in Refinery CO₂ Emissions as a Result of Marginal Change in Gasoline/Diesel Production
- **Change in Gasoline/Diesel Production (%)**
- **Median Change in Refinery CO₂ Emissions (%)**

- **Gasoline**
  - Linear: Increasing
  - Regulatory Approach: GREET 2014 = 20.6, EPA RFS 2 = 18.2

- **Diesel**
  - Linear: Increasing
  - Regulatory Approach: GREET 2014 = 17.0, EPA RFS 2 = 17.1
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Implications - Overall Transport Efficiency.
Shifting the Burden Further Downstream to the Transport Sector

**BUT, Diesel Engines are More Efficient...**

![Comparison of gasoline and diesel vehicles](image)

<table>
<thead>
<tr>
<th>Diesel</th>
<th>Premium Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPG</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>27</td>
</tr>
<tr>
<td>city/highway</td>
<td>combined</td>
</tr>
<tr>
<td>31/42</td>
<td>23/35</td>
</tr>
<tr>
<td>city</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>3.7</td>
</tr>
<tr>
<td>gal/100mi</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Range</td>
<td></td>
</tr>
<tr>
<td>525 miles</td>
<td>427 miles</td>
</tr>
</tbody>
</table>

Source: US EPA FuelEconomy
http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=36793&id=36792

**Road Transport Sector**
Optimised Refinery Production Scenario

- **Assumption:** Average MPG for gasoline and diesel cars are 24.8 and 29.8, respectively

Combining CO₂ Emissions from Diesel and Gasoline Cars (gCO₂/100 km)

**BUT** reversing dieselization can worsen CO₂ emissions from road transport.
Final Thoughts - Optimizing Transport Efficiency.
Gasoline-like Fuel in a Diesel-like Compression Ignition Engine