Thriving in the Energy Transition – Pathways to a Low Carbon Future

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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 2P and 2C 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.

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Shell’s Purpose

We power progress together by providing more and cleaner energy solutions

**LET’S MAKE THE FUTURE**
Thrive in the energy transition

**Societal challenge**

<table>
<thead>
<tr>
<th>2015</th>
<th>2070</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing population</td>
<td>&gt;10 billion</td>
</tr>
<tr>
<td>7 billion</td>
<td></td>
</tr>
</tbody>
</table>

Increasing energy demand

<table>
<thead>
<tr>
<th>2015</th>
<th>2070</th>
</tr>
</thead>
<tbody>
<tr>
<td>570 Exajoules</td>
<td>1000 Exajoules</td>
</tr>
</tbody>
</table>

Need to reduce CO₂ emissions

<table>
<thead>
<tr>
<th>2015</th>
<th>2070</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 gt CO₂e</td>
<td>43 gt CO₂e</td>
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</tbody>
</table>

Net Zero Emissions

CO2 Emission Pathways

- History
- Unconstrained (MIT)
- Oceans (Shell)
- Mountains (Shell)
- Target 2°C (MIT)
- Paris National 1.5°C Pathway
- Paris Range 1.5°C - 2°C

CO2 Emission Pathways
Thrive in the energy transition

Ambition - Net Carbon Footprint

Ambition to reduce Net Carbon Footprint\(^1\) of our energy products by around 20% by 2035

- Covers full range of emissions from energy products
- Aim to reduce overall intensity including production, supply chain, and customers
- Government policy, technology, and consumer choice will drive actual energy transition pace and outcomes
- Drive strategy over time in step with society
- 5-year reviews to ensure in line with societal progress

<table>
<thead>
<tr>
<th>Year</th>
<th>Society trajectory(^2)</th>
<th>Shell trajectory(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
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<tr>
<td>2030</td>
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<td>2035</td>
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<td></td>
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<tr>
<td>2045</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Net Carbon Footprint measured on an aggregate “well to wheel” or “well to wire” basis, from production through to consumption, on grams of CO\(_2\) equivalent per megajoule of energy products consumed; chemicals & lubricants products are excluded. Carbon Footprint of the energy system is modelled using Shell methodology aggregating lifecycle emissions of energy products on a fossil-equivalence basis. The methodology will be further reviewed and validated in collaboration with external experts.

2. Potential society trajectory includes analysis from Shell scenarios estimate of Net Zero Emissions by 2070 and IEA Energy Technology Perspectives 2017; Potential illustrative Shell trajectory.

Royal Dutch Shell | November 28/29, 2017
Thrive in the energy transition

**Ambition – Net Carbon Footprint**

- Flexibility and mix of options to achieve ambition
- Allows for oil and gas production growth offset by evolving product mix
- Changing product mix gives greatest opportunity
- Top-quartile scope 1 + 2 emissions has limited overall impact

**Potential tools to achieve our 2035 Net Carbon Footprint**

<table>
<thead>
<tr>
<th>Tool</th>
<th>Baseline</th>
<th>Top quartile (Scope 1+2)</th>
<th>Natural gas shift</th>
<th>New energy</th>
<th>Biofuels</th>
<th>Electric mobility</th>
<th>CCS</th>
<th>Natural sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTW gCO₂e/MJ</td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>60</td>
<td>50</td>
<td>40</td>
<td>30</td>
<td>2035 AMBITION</td>
</tr>
</tbody>
</table>

**Existing examples:**

- Flare reduction
- Increased LNG
- Wind power
- Raizen biofuels
- Shell Recharge + New Motion
- Quest CCS
- Nature based offsets

Shell is active in each of these areas

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New Energies

Emerging Opportunities

New Fuels

- Build integrated value chains
- Exploit adjacencies to existing businesses
- Discipline and commerciality
- Not equipment manufacturing

Focus areas:
- Biofuels
- Hydrogen

Power

Focus areas:
- Trading, marketing and customer access
- Low-carbon generation and storage (solar, wind, gas)
Shell and Biofuels

Trading & Supply
One of the world’s largest blenders and distributors of biofuels

Raízen JV
Production of low-carbon ethanol from Brazilian sugar cane

Advanced Biofuels
Investing in technologies using alternatives feedstocks such as waste

Sustainability
Commitment to the supply and development of sustainable biofuels
Hydrogen as a transport fuel
Clean and convenient

- Improves local air quality.
- Only water vapour emissions while driving.
- Low-carbon transport in the longer term.
- Can help reduce CO₂ emissions if made from renewable or low carbon sources.
- High range – up to 700 km per refuel
- Minutes to refuel
Shell and hydrogen

**Germany**

- **H2 Mobility Germany**
  - (230 Shell-branded)

**California, USA**

- **Shell Retail Stations**
  - Two Shell refuelling Stations – Torrance and Newport Beach.

**UK**

- **First Shell hydrogen station in 2017 – London, UK.**

**Toyota Partnership**

- Seven retail stations to be owned/operated by Shell.
Portfolio resilience through a **Power value chain**

**CUSTOMERS**
Multiple parties are active on the demand side

- Secure demand in key markets
- Commercial, industrial, and residential

**OPTIMISATION**
Leverage portfolio flexibility and arbitrage opportunities

- Optimise intermittent demand and supply
- Trading opportunities

**SUPPLY & GENERATION**
Not all products are supplied by Shell; some are purchased from third parties

- Wind, solar, and selected gas and storage assets
- Selective capacity ownership to create portfolio flexibility

- Adjacencies to existing gas businesses
- Value chain integrator
- Demand-driven development
Wind
Experience and portfolio diversity

Wind is an increasingly prominent part of the evolving energy system

- More than 15 years’ experience.
- Onshore and offshore projects operational in the USA and in Europe (50:50 joint ventures).
- Working to develop a diverse portfolio in offshore wind.

**Onshore US**
Since 2001; 553 wind turbines
Capacity: 738 MW (Shell Share: 369 MW)

**Offshore Europe**
Since 2007; 36 wind turbines
Capacity: 108 MW (Shell Share: 54 MW)

**Offshore Europe (in development with consortium)**
The Netherlands, 680 MW
Solar
Providing tailored, integrated solutions for our customers

Investing in those opportunities where we:

See the potential for scale
Have line of sight to profitability
Can leverage Shell’s existing footprint and capabilities
The Pace of Energy Decarbonization will vary by Industry Sector

- **Built environment**: 9.3Gt
- **Industry**: 13Gt
- **Transport**: 8.5Gt
- **Power generation**: 13.6Gt

Colors indicate:
- **Green**: Less difficult to decarbonise
- **Yellow**: ... (Neutral)
- **Red**: More difficult to decarbonise
Aviation, Shipping & Long Distance Transport will still need Liquid Fuels
Policy coordination vs technology
A journey to net-zero emissions

Source: Shell FET analysis

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Long Range Research (LRR) – Back to Basics and Fundamental R&D

New Energy
- Develop a radically better energy carrier using low cost solar energy combined with novel technologies for energy storage and conversion

Chemicals
- Find new pathways to convert methane to products

Enabling sciences
- Electrochemistry
- Materials science
- Structured catalysts & interfacial phenomena
- Transport phenomena
- Computational material science & chemistry
- Biosciences

Emphasis on scientific areas where: (i) we want to build capability; (ii) there is significant innovation headroom; (iii) it has impact across multiple applications
Dense Energy Carriers (Solar Fuels)

Efficient Water Splitting

CO\textsubscript{2} Capture from Ambient

Routes to Fuels Synthesis

Hydrocarbons

Low Cost PV

Electrons

Hydrogen

TO END-USER

- Power
- Cooking
- Heating/Cooling

TO END-USER

- Personal mobility
- Heavy transport
- Industrial heat
- Power
- Rail

Artificial Photosynthesis

Highest energy utilization
Lowest production costs
Smallest production footprint
PV Auction Database: PPA prices decline

Source: Official government publications, World Bank, IFC, BNEF, various news sources

Latest 3 bids <30$/MWh
Dense Energy Carrier – recent insights

Solar PV <2 cents/kWh feasible by 2025

Cost of CO₂ direct Air Capture < $150/ton by 2030

Electrolytic hydrogen may be produced at ~ $1/kg by 2035; I.E. cost competitive to H₂ from SMR (With CCS)

But… will we be able to create an End-to-End solution for an affordable, safe and ubiquitous energy carrier that challenges the convenience of liquid hydrocarbons?
Li-ion is ahead in the adoption game and “improved Li-ion” may become leading technology for increasing number of applications.

Technology learning curves make deployment pace a competitive advantage (‘winner takes all’).

Energy storage deployment over time

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Source: BNEF, April 2015
Advanced Energy Storage (AES)

Research Directions

- Safety
  - Solid-state systems
  - Reduce short circuits

- Cost
  - Abundant feedstocks

- Cycle Life
  - Stability & fidelity of structures & phases

- Energy Density
  - Metal anodes
  - Multivalent chemistries

- Power Density
  - Supercapacitors
  - New approaches to charge transfer

- Charge Time
  - Minimize side reactions

- Charge Time
  - Minimize side reactions

Global Partners

- Answer fundamental questions about electrochemical energy storage materials and devices
- Focus on phenomena that give insights across a range of chemistries to direct future research & support business decisions
- Collaborative projects executing in US, UK, & NL; internal patent filings also in progress
The Global Market for Chemicals Continues to Grow

**LNG regasification capacity**
mln tonnes p.a.

**Domestic demand for base chemicals**
mln tonnes p.a.

Source: Shell Management Day Nov 2015

Source: IHS
Methane to Products (M2P)

- Current markets for methane/natural gas is dominated by its calorific value (energy content)
- Find new routes for monetizing natural gas reserves
  - Bulk chemicals (‘advanced feedstock’)
  - Carbon as construction material (and H₂)
- Assume increased CO₂ taxation, instead of no penalty (for DEC/AES)
  - Ideally products with long life-time (reducing CO₂ penalty)
- Explore new scientific developments within catalysis, materials, physics
- Time-line: decades, but probably shorter
Long Range Research Technology Platform

**PROGRAMS**
- Dense Energy Carriers
- Advanced Energy Storage
- Methane to Products

**ENABLING CAPABILITIES**
- Computational Material Science & Chemistry
- Bio-Sciences & Bio-Engineering
- Exploratory Experimentation
The Energy Transition ...... Coming Full Circle in the Near Future
Summary

- Energy systems are becoming ever more decentralised and interconnected.
- Shell aims to become a global leader in cleaner power generation, taking advantage of our global footprint and experience with large-scale power infrastructure.
- Natural gas and energy storage solutions must integrate with renewables to meet customers' new energy needs.
- Our integrated approach explores and expands wind and solar; ways to connect customers with new business energy models; access to energy; and the digitalisation of businesses.
Questions and Answers