R&D Webcast for Investors and Analysts on January 10, 2019

Carbon Management at BASF – R&D strategies to reduce CO$_2$

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Cautionary note regarding forward-looking statements

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BASF as a pioneer in developing tools for sustainability performance measurement

Systematic application of sustainability measurement since 1996

- Eco-Efficiency Analysis
- SEEBALANCE®
- Corporate Carbon Footprint
- AgBalance™
- Biomass Balance Certification
- Sustainable Solution Steering®
- Investment evaluation
- Advanced IT solutions for customers
- Carbon Management Value-to-Society

Products in the value chain

- Corporate
- Portfolio and digital solutions
The Carbon Dioxide Challenge

BASF’s Carbon Management

Outlook
The Carbon Dioxide Challenge

BASF’s Carbon Management Outlook
Global greenhouse gas (GHG) emission scenarios

**Global GHG emissions in % (Reference 1990)**

- **Global GHG emissions 1990:** 36.4 metric gigatons
- **Reference (Currently intended policy):** Risk of 3.8 – 4.7°C
- **Policy for 2°C scenario:** Around 3°C

Source of global GHG emissions and future scenarios: JRC Global Energy and Climate Outlook 2016

*Implementation of Nationally Determined Contributions as expressed in Paris Agreement*
BASF’s successful greenhouse gas reduction

Since 1990, BASF has halved its emissions and doubled its sales volume

BASF’s output in 1990

40 mt CO₂
2.2 tons per ton

BASF’s output in 2018

22 mt CO₂
0.6 tons per ton

“mt” = million metric tons, “tons per ton” = metric tons CO₂ equivalents per metric ton sales product
BASF’s carbon footprint 2017 and established measures

BASF commits to CO₂-neutral growth in its new corporate strategy. This requires a new approach to Carbon Management.

"mt" = million metric tons  * thereof 36 mt from BASF’s oil and gas business
BASF’s Carbon Management aims to decouple growth from CO₂ emissions

Established measures
- Biomass balance
- Bio-based products and materials

New measures
- ChemCycling
- Renewable energy

Source

Make
- Verbund concept and process optimization
- CO₂ as a feedstock

Use
- CO₂-saving BASF products and solutions

End-of-life
- Biodegradable BASF products and materials
- New CO₂-saving BASF products and solutions
- Close-the-loop solutions
- ChemCycling
The Carbon Dioxide Challenge

BASF’s Carbon Management

Avoid CO$_2$ on site

Use CO$_2$ as a feedstock

Help customers avoid CO$_2$ (Accelerator products)

Outlook
BASF’s sales products in a nutshell

Chemical formula: \((\text{C H}_{3.1}\text{O}_{0.3}\text{N}_{0.2}\ X )_n\)

Composition:
- Carbon
- Hydrogen
- Oxygen
- Nitrogen
- Others

Raw materials:
- Naphtha, natural gas, renewables, recycled waste, CO₂
- Air
- Others

Chemistry is based on carbon and cannot be “decarbonized.”
BASF’s Carbon Management targets fugitive carbon

Carbon

\[ \text{CO}_2 = \text{fugitive carbon} \]

25% \rightarrow \text{Chemicals} \rightarrow 75%

A Verbund is the ideal setup for Carbon Management.
BASF’s Verbund avoids CO₂
The full picture – for ethylene
BASF’s Verbund avoids CO$_2$
Synergies among selected value chains

A Verbund optimizes the use of products and utilities.
BASF’s Verbund avoids CO₂ Examples

In total, BASF’s Verbund in Ludwigshafen avoids around 6 mt of CO₂ emissions.

“kt” = thousand metric tons, “mt” = million metric tons
BASF’s Carbon Management

Measures at a glance

**CO₂ emitters:**

- Power plants
- Steam cracker
- Ammonia/hydrogen
- N₂O
- Others

**Measures:**

- Process optimization, energy management, N₂O decomposition
- Clean hydrogen research, E-Furnace research, clean olefins research
- Purchase of renewable energy

BASF’s Carbon Management includes process optimization, technology research and the supply of renewable energy.
The Carbon Dioxide Challenge

BASF’s Carbon Management

Avoid CO$_2$ on site

Use CO$_2$ as a feedstock

Help customers avoid CO$_2$ (Accelerator products)

Outlook
Chemistry is energy

Thermodynamics of water electrolysis

\[
\Delta H^\circ = +286 \frac{\text{kJ}}{\text{mol H}_2}
\]

\[ \text{H}_2^\text{(g)} + 0.5 \text{O}_2^\text{(g)} \]

Thermodynamics of CO\textsubscript{2} formation

\[
\Delta H^\circ = -803 \frac{\text{kJ}}{\text{mol CH}_4}
\]

\[ \text{CH}_4^\text{(g)} + 2 \text{O}_2^\text{(g)} \]

Water and carbon dioxide are very stable molecules. Using them as chemical raw materials is very energy-intensive.
Using CO\textsubscript{2} as a feedstock is energy-intensive
Viable options are therefore limited

- Hydrocarbons
- Industrial chemicals
- Carbohydrates
- Urea
- Synfuels
  - E.g., acrylic acid
  - BASF invests in R&D
- Photosynthesis
  - BASF produces wood binders
- Global CO\textsubscript{2} consumption: 115 mt p.a.
  - BASF produces AdBlue®

BASF is exploring new processes to make specialty chemicals from CO\textsubscript{2}.

"mt" = million metric tons
Limited potential to use CO₂ as a feedstock in the chemical industry

CO₂ emissions in Germany 2017: 905 mt CO₂

Chemical production in Germany 2017: 48 mt CO₂eq

We need new breakthrough technologies to significantly reduce the CO₂ footprint.

“mt” = million metric tons
The Carbon Dioxide Challenge

BASF’s Carbon Management

Avoid CO₂ on site
Use CO₂ as a feedstock
Help customers avoid CO₂ (Accelerator products)

Outlook
CO$_2$-saving innovative solutions

Mineral-based in-situ foam: Cavipor$^\text{®}$

Enabling e-mobility: Cathode active materials
The Carbon Dioxide Challenge

BASF’s Carbon Management

Avoid CO\textsubscript{2} on-site
Use CO\textsubscript{2} as a feedstock
Help customers avoid CO\textsubscript{2} (Accelerator products)

Outlook
BASF’s new CO₂ emission target

Baseline 2018

-33% specific emissions

+50% sales products

Our target 2030:
CO₂-neutral growth
BASF’s new CO₂ emission target

Until 2030, BASF aims to grow its output by 50% without increasing its CO₂ emissions.

2.2 tons per ton

40 mt CO₂

2018*

22 mt CO₂

0.6 tons per ton

2030

22 mt CO₂

0.4 tons per ton

*mt* = million metric tons, *tons per ton* = metric tons CO₂ equivalents per metric ton sales product  * forecast
BASF’s Carbon Management – our focus today

Potential CO₂ reduction

- Further improve process and energy efficiency
- Shift power supply towards renewable energies
- Develop CO₂-reduced breakthrough technologies

powered by BASF’s unique catalyst platform

Costs and risks
E-Furnace: New technology for clean high-temperature reactions

BASF aims to develop the world’s first electrical heating concept for steam crackers (1,000°C) within the next five years. This requires the redesign of the entire furnace from the alloy composition to electric connectors and transformers.*

Approach:

- Switch cracker coil heating from natural gas to electrical resistance heating, combining high current with low voltage
- Integrate an E-Furnace – to be newly engineered – into the steam cracker in Ludwigshafen

Next milestone:

- Proof of material for steam cracker coils, i.e., study interaction of coil alloy with applied electric power

*N: Government funding will be necessary due to high technological and commercial risk
Methane pyrolysis:
New process for clean hydrogen

Approach:
- Decompose methane (CH₄) into hydrogen and solid carbon via thermal pyrolysis avoiding CO₂ as byproduct
- Design a moving carbon bed reactor that combines chemical reaction and heat integration

Next milestone:
- Proof of the heating concept, i.e., overcome carbon deposition, inhomogeneous flow and pulsations inside the reactor

BASF is developing a completely new reactor design for the pyrolysis of methane into hydrogen and solid carbon* and is evaluating options to utilize the byproduct solid carbon.

* Government funding will be necessary due to high technological and commercial risk
**Dry reforming of methane and direct conversion of syngas to DME: New catalysts for clean olefins**

- **Approach:**
  - Switch feedstock for olefins from naphtha to methane
  - Produce CO-rich syngas via dry reforming of methane and convert the syngas into dimethyl ether (DME), an established precursor for olefins

- **Next milestone:**
  - Production trial for CO-rich syngas and completion of DME upscaling

BASF will commercialize its new generation of catalysts for the dry reforming of methane (planned for 2020) and the direct conversion of CO-rich syngas to DME (planned for 2022) in collaboration with Linde.
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CO₂ as feedstock for superabsorbents: New chemistry for using CO₂

Approach:
- Evaluate the thermodynamically favored reaction of CO₂ with ethylene to sodium acrylate, which is the main raw material for superabsorbents
- Switch feedstock for superabsorbents from C3 (propylene → acrylic acid) to C2 + CO₂ (ethylene + CO₂ → sodium acrylate)

Next milestone:
- Catalyst activity and lifetime as well as energy demand for the base regeneration in target range

BASF is developing an industrial process for the catalytic formation of sodium acrylate based on CO₂ and ethylene.