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

Carbon Management at BASF – R&D strategies to reduce CO₂

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Cautionary note regarding forward-looking statements

This presentation contains forward-looking statements. These statements are based on current estimates and projections of the Board of Executive Directors and currently available information. Forward-looking statements are not guarantees of the future developments and results outlined therein. These are dependent on a number of factors; they involve various risks and uncertainties; and they are based on assumptions that may not prove to be accurate. Such risk factors include those discussed in the Opportunities and Risks Report from page 111 to 118 of the BASF Report 2017. BASF does not assume any obligation to update the forward-looking statements contained in this presentation above and beyond the legal requirements.
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BASF as a pioneer in developing tools for sustainability performance measurement

Systematic application of sustainability measurement since 1996
The Carbon Dioxide Challenge

BASF’s Carbon Management

Outlook
The Carbon Dioxide Challenge

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

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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

Global GHG emissions 1990: 36.4 metric gigatons

Global GHG emissions in % (Reference 1990)

- Reference
- Currently intended policy*
- Policy for 2°C scenario

- Risk of 3.8 – 4.7°C
- Around 3°C
- 2°C

Global GHG emissions

2°C
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

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

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

59 mt CO₂

23 mt CO₂

43* mt CO₂

20 mt CO₂

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**
- Established measures

**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

**Carbon Management Program**
- New CO₂-saving BASF products and solutions
- Close-the-loop solutions
- ChemCycling

**Carbon Management Program**
- New CO₂-saving BASF products and solutions
- Close-the-loop solutions
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The Carbon Dioxide Challenge

BASF’s Carbon Management

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

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

A Verbund optimizes the use of products and utilities.
In total, BASF’s Verbund in Ludwigshafen avoids around 6 mt of CO$_2$ emissions.
BASF’s Carbon Management Measures at a glance

CO\textsubscript{2} emitters:

- Others
- N\textsubscript{2}O
- Ammonia/hydrogen
- Steam cracker
- Power plants

Measures:

- Process optimization, energy management, N\textsubscript{2}O 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

\[
\text{H}_2(g) + 0.5 \text{O}_2(g) \xrightarrow{\Delta H_f^0 = +286 \text{ kJ/mol } \text{H}_2} \text{H}_2\text{O}(l)
\]

Thermodynamics of CO\(_2\) formation

\[
\text{CH}_4(g) + 2 \text{O}_2(g) \xrightarrow{\Delta H_f^0 = -803 \text{ kJ/mol } \text{CH}_4} \text{CO}_2(g) + 2 \text{H}_2\text{O}(g)
\]

Water and carbon dioxide are very stable molecules. Using them as chemical raw materials is very energy-intensive.
Using CO₂ as a feedstock is energy-intensive
Viable options are therefore limited

BASF is exploring new processes to make specialty chemicals from CO₂.

Energy

- Hydrocarbons
- Industrial chemicals
- Carbohydrates
- Urea

Synfuels
- E.g., acrylic acid
  → BASF invests in R&D

Photosynthesis
  → BASF produces wood binders

Global CO₂ consumption: 115 mt p.a.
  → BASF produces AdBlue®
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.
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®

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

BASF’s Carbon Management

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

Outlook
BASF’s new CO₂ emission target

Baseline 2018

+50% sales products

-33% specific emissions

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.

25 *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

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

powered by BASF’s unique catalyst platform
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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

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*Government funding will be necessary due to high technological and commercial risk*
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.

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

* 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.
BASF is developing an industrial process for the catalytic formation of sodium acrylate based on CO\textsubscript{2} and ethylene.

**Approach:**
- Evaluate the thermodynamically favored reaction of CO\textsubscript{2} with ethylene to sodium acrylate, which is the main raw material for superabsorbents
- Switch feedstock for superabsorbents from C3 (propylene $\rightarrow$ acrylic acid) to C2 + CO\textsubscript{2} (ethylene + CO\textsubscript{2} $\rightarrow$ sodium acrylate)

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