Hearing of the Consultative Commission on Industrial Change

Modern Use of Lignite

Michael Eyll-Vetter, Vice President Mine Planning

Brussels, 14 September 2015

RWE
The energy to lead
Rhenish lignite mining area -
3 billion tons of lignite reserves approved for extraction

Lignite system
- Lignite output: ~ 90 – 100 Mt/a
- Power generation_{net}: ~ 70 – 75 TWh/a
- Refined products: ~ 5.5 Mt/a for distributed use
- ~ 10,500 employees (incl. trainees)

<table>
<thead>
<tr>
<th>Unit class</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>300MW</td>
<td>1/3</td>
</tr>
<tr>
<td>600MW</td>
<td>1/3</td>
</tr>
<tr>
<td>1,000MW (BoA)</td>
<td>1/3</td>
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</tbody>
</table>

Weisweiler/Inden isolated operations
- Capacity: ~ 1,900 MW_{gross}
- Generation: ~ 14 TWh/a_{net}

<table>
<thead>
<tr>
<th>Mine</th>
<th>Output</th>
<th>Reserves</th>
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</thead>
<tbody>
<tr>
<td>Garzweiler</td>
<td>35 – 40 M t/a</td>
<td>1.2 bnt</td>
</tr>
<tr>
<td>Hambach</td>
<td>35 – 45 M t/a</td>
<td>1.4 bnt</td>
</tr>
<tr>
<td>Inden</td>
<td>20 – 25 M t/a</td>
<td>0.3 bnt</td>
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</tbody>
</table>

*according to unit classes
Modernisation of the power plant fleet resulting in substantial CO₂ reductions

Key contents of the 1994 power plant renewal programme

> Power plant renewal using the best technology available at the time
  − Optimised concepts
  − Optimum fuel use
  − Significant contribution to climate protection
  − Reduction of other emissions

> Step by step until 2030
> With economic efficiency as a prerequisite
> RWE investment volume: about €10 billion

So far, the programme has been implemented as planned (BoA 1-3 etc.) with investment totalling over €4.3 billion
Power plant renewal progressing as planned
BoA* 1-3 make lignite fit for the future

- 3,000 MW in new-build units (BoA 1-3) started operation between 2003 and 2012; highest standard for lignite-fired plants world-wide

- All sixteen 150 MW units in the Frimmersdorf, Niederaussem and Weisweiler power plants were finally closed down on 31/12/2012

- CO₂ savings of some 9 Mt/a

Approval procedure for BoAplus involving a further efficiency boost is underway

* Braunkohlekraftwerk mit optimierter Anlagentechnik
(lignite-fired power plant with optimised plant engineering)
Continuous efficiency increase

With its integrated firing concept, BoAplus is setting a new efficiency standard for lignite-based power generation world-wide.
Flexible lignite-fired power plants

BoA 1-3 new-builds

Planning and approval of BoAplus

Modernisation of existing power plants

Lignite is becoming a strong and reliable partner to renewables, balancing fluctuating PV- and wind-based power generation.

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Max. Capacity</th>
<th>Min. Capacity</th>
<th>Max. Load Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lingen CCGT plant</td>
<td>~ 2x440 MW</td>
<td>~ 520/260* MW</td>
<td>+/- 32 MW/min</td>
</tr>
<tr>
<td>BoA 1 - 3 lignite plant</td>
<td>~ 1,000 MW</td>
<td>~ 500 MW</td>
<td>+/- 30 MW/min</td>
</tr>
<tr>
<td>BoAplus lignite plant</td>
<td>~ 2x550 MW</td>
<td>~ 350/175* MW</td>
<td>+/- 30 MW/min</td>
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</tbody>
</table>
**BoAplus**
Less lignite consumption, less CO$_2$, less emissions

### Higher efficiency: over 45%

<table>
<thead>
<tr>
<th></th>
<th>BoAplus</th>
<th>300MW</th>
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</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>&gt; 45%</td>
<td>~ 33%</td>
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</tbody>
</table>

Increase in efficiency of about 30% to an overall efficiency of > 45%.

### Result

**Fuel input: 30% less**

- Compared with the four 300 MW units to be shut down, fuel input is reduced by 30%.

**CO$_2$ emissions: 30% less**

- Compared with the four 300MW units to be shut down, CO$_2$ emissions are reduced by approximately 30% or 3 Mt/a.

### Less emissions
Sulphur oxides, nitrogen oxides, particulate matter (examples)
The refining business offers additional markets

Raw lignite input of ~ 15 Mt/a

- Refining to make pulverised lignite and fluidised-bed lignite, lignite briquettes and lignite coke of about ~ 5.5 Mt/a
- Generation and external marketing of ~1.1 TWh$_{th}$ heat/a
- Power generation (net) of 1.9 TWh/a

Refining offers opportunities for value creation outside the electricity market
Research and Development potential – Focus on three key areas

Stabilising current business – high-performing partner
Maintaining acceptance – most trusted partner
Responding to shrinking power market – create value-adding products

<table>
<thead>
<tr>
<th>1</th>
<th>Lignite use</th>
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<tbody>
<tr>
<td>• Lignite preparation and drying</td>
<td></td>
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<tr>
<td>• Lignite demineralisation</td>
<td></td>
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<tr>
<td>• Biomass preparation</td>
<td></td>
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<tr>
<td>• Lignite slurry</td>
<td></td>
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<tr>
<td>• Coal-to-Gas</td>
<td></td>
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<tr>
<td>• Coal-to-Liquid</td>
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<table>
<thead>
<tr>
<th>2</th>
<th>Power plant technology</th>
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<tbody>
<tr>
<td>• Flexibility increase</td>
<td></td>
</tr>
<tr>
<td>• Efficiency boost</td>
<td></td>
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<tr>
<td>• Plant concepts</td>
<td></td>
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<tr>
<td>• System evaluation</td>
<td></td>
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<tr>
<td>• Combustion</td>
<td></td>
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<tr>
<td>• Co-combustion</td>
<td></td>
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<tr>
<td>• Coal quality</td>
<td></td>
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<tr>
<td>• Ash landfills</td>
<td></td>
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<td>• Damage analysis</td>
<td></td>
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<thead>
<tr>
<th>3</th>
<th>Flue gas cleaning</th>
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<tbody>
<tr>
<td>• CCS strategy</td>
<td></td>
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<tr>
<td>• CO$_2$ transport and storage</td>
<td></td>
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<tr>
<td>• PCC pilot plants</td>
<td></td>
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<tr>
<td>• CO$_2$ filling station</td>
<td></td>
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<tr>
<td>• Particulate removal</td>
<td></td>
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<tr>
<td>• Desulphurisation</td>
<td></td>
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<tr>
<td>• NOx removal</td>
<td></td>
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<tr>
<td>• Mercury reduction</td>
<td></td>
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<tr>
<td>• REAplus pilot plant</td>
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Lignite can help replace gas and oil in the manufacture of a wide variety of products. Example: CtL/CtG process.

Key technologies:
- Drying
- Gasification
- Gas treatment
- Synthesis

Alternative routes:
- Synthesis gas
- Ammonia
- Methane
- Methanol
- Basic chemicals*
- Motor fuels
- Waxes

Other energy sources:
- Option: H₂ use

* Naphtha, acetic acid, formic acid, carboxylic acid, hydrogen, …
Lignite can make important contributions to long-term security of supply

> Approved reserves form a sound basis for cost-efficient lignite mining and use

> Lignite-fired power plants are as flexible as modern gas stations, which makes them an ideal partner to renewables

> According to current studies, lignite continues to be necessary in terms of energy policy and energy management for the supply of Germany/North Rhine-Westphalia to secure their viability as industrial locations over the long term

> As a domestic raw material, lignite reduces Germany's import dependence

> Power plant renewal is to be continued

> Lignite is converted by refining into a wide variety of secondary products, e.g. pulverised lignite for use in large industrial combustion plants, and has the potential to replace mineral oil and natural gas in the (petro)chemical industry
Back-up
Overview of the power plant fleet

- 2,100 MW (BoA 2&3)
- 1,000 MW (BoA 1)
- 6 x 600 MW (Ø 40 years)
- 11 x 300 MW (Ø 46 years)
- 150 MW units

- ~ 1/3 new-build, cutting-edge power plants
- ~ 1/3 refitted with new technology
- ~ 1/3 to be optimised or replaced in a next step
- Shut down
Binding commitment to shutdowns

Upon the start of commercial BoAplus operation, more than the same capacity (four 300 MW units) will be shut down
Lignite utilization options exist far beyond power production

- Domestic lignite is a large energy and raw material source, which currently serves the power and heat market
- RWE owns significant lignite assets in NRW
- Due to the increase of efficiency of our lignite power plant fleet and a projected decrease of power production from lignite, it is expected that significant amounts of mining capacities will be available in the mid- to long-term
- To sustain a cost competitive power production from lignite it is helpful to keep a high degree of capacity utilization in our lignite mines
- Free mining capacities should therefore be used for alternative routes of lignite utilization if economically feasible
- Conversion of lignite to basic chemical materials, fuels, or other energy carriers via gasification is an option to make use of millions of tons of lignite in the mid- to long-term
- RWE does have significant know-how in gasification and synthesis of chemicals or energy carriers from lignite
- Bandwidth of products from lignite is large, e.g.: synthetic natural gas, naphtha, ammonia, urea, methanol, fuels, waxes, ...

- Lignite bears the potential to substantially replace crude oil and natural gas in (petro-) chemical industry, thus alternative use of lignite can help to stabilize current exploitation rates of our open cast mines
Lignite can help replace gas and oil in the manufacture of a wide variety of products

- In principle, supply ranging from raw lignite via intermediate products to various end products is conceivable.
- Important intermediate product is synthesis gas (hydrocarbon mixture) that is produced by lignite gasification and further treatment and can be used as a basic substitute for crude oil or natural gas.

![Flowchart showing the process from raw lignite to various products like synthesis gas, methanol, and gasoline, with various treatment processes highlighted.](image-url)
The economic perspectives of CtL are good.

Example: Fischer-Tropsch naphtha

- Economic efficiency possible under certain boundary conditions
- Important levers:
  - Euro exchange rate
  - Financing options/interest rate
  - Economies of scale/use of existing infrastructure
  - CO₂ allowances costs
  - Shale gas/shale oil in Europe
  - Oil price shocks and dips

Economic perspective is seen for CtL/CtG in the medium to long term.

*Calculation basis: 500MW<sub>th</sub>, 1.3Mt dry lignite/a, €525m in capex, annex concept
Transformation of carbon sources

Challenge for lignite:
- Conversion of solid fuels into liquid or gaseous secondary energy sources
  ≅ Adjustment of the H:C:O ratio
- Solid fuels with "too much" oxygen (O) and carbon (C) and "too little" hydrogen (H)
  → Change in ratio, among others through shift reaction
  → Addition of renewables-based H₂ also conceivable

Opportunity:
- Manufacture of carbonaceous products from lignite reduces emissions (carbon sink) compared with combustion

Methanol production (example):

\[
\text{C}_5\text{H}_4\text{O} + 2\text{H}_2\text{O} + \frac{5}{2}\text{O}_2 \rightarrow \text{2CO} + 4\text{H}_2 \rightarrow \text{2CH}_3\text{OH} + 3\text{CO}_2
\]

⇒ min. 40% carbon sequestration
Product yield and market shares for an input of 10 million tons of raw lignite

<table>
<thead>
<tr>
<th>Lignite product</th>
<th>Typical end product/sales market</th>
<th>Yield</th>
<th>Market share (country)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>incl.*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>naphtha</td>
<td>Plastics</td>
<td>9Mbbl</td>
<td>e.g. naphtha 2% (D)</td>
</tr>
<tr>
<td>waxes</td>
<td>Lubricants, candles, cosmetics</td>
<td>3Mbbl</td>
<td></td>
</tr>
<tr>
<td>middle distillates</td>
<td>Diesel, kerosene</td>
<td>3Mbbl</td>
<td></td>
</tr>
<tr>
<td>Acetic acid</td>
<td>Paints, adhesives, artificial silk</td>
<td>3.9Mt</td>
<td>30% (global)</td>
</tr>
<tr>
<td>Formic acid</td>
<td>Solvents, textile and leather processing</td>
<td>7Mt</td>
<td>1,000% (global)</td>
</tr>
<tr>
<td>Motor fuel</td>
<td>Gasoline</td>
<td>6.0Mbbl</td>
<td>3.5% (D)</td>
</tr>
<tr>
<td>Urea</td>
<td>Fertiliser</td>
<td>4.0Mt</td>
<td>3% (global)</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Energy source, refining of hydrocarbons</td>
<td>0.5Mt</td>
<td>25% (D)</td>
</tr>
<tr>
<td>Syngas</td>
<td>Heat market, synthesis gas production, electricity</td>
<td>2.0Mcbm</td>
<td>2% (D)</td>
</tr>
</tbody>
</table>

Products from domestic lignite can replace some of the oil and gas product quantities used.

* Product breakdown depends on the catalyst used and can vary substantially
For CtL/CtG implementation, R&D must focus on three key areas

**Key technologies**

- **Gas treatment**
- **Gasification**
- **Drying**

**Synthesis gas**

**Lignite**

**Alternative routes**

- **Ammonia**
- **Methane**
- **Methanol**
- **Basic chemicals**
- **Motor fuels**
- **Waxes**

**Coal gasification – lever for capex optimisation**

- Increase in efficiency, robustness, economy of scale
- Confirmation of functioning with domestic lignite

**Syntheses – lever for the manufacture of high-quality products**

- Process adjustment to customers' product requirements
- Efficiency boost by avoiding intermediate products

**Hydrogen supply – lever for emission reduction**

- Future use of renewables-based hydrogen calls for the development of low-cost electrolyses

* Naphtha, acetic acid, formic acid, carboxylic acid, hydrogen, …
Our vision: Availability of CtL/CtG for Rhenish lignite by 2025

Particular challenge: Economic integration of new plant technology into existing infrastructure in the lignite and chemical industries

- The technologies used in CtL/CtG plants are commercially available in principle.
- But adjustment to the Rhenish lignite's typical characteristics and to requirements in Germany plus testing is required.

* Thermal gasifier capacity is a reference value for overall plant size
Annex principle: Integration of CtL/CtG plants into existing site infrastructure …

- reduces investment costs compared with a stand-alone solution
- offers new use/operating options for existing infrastructure

Power plant and industrial sites offer potential for annex solutions.
RWE is looking for partners to develop and implement CtL/CtG options.
BoAplus Niederaussem
Cornerstones of the further-developed concept

2 x 550MW boiler
- High flexibility
- Reduced overall height (~ 100m)

Hybrid cooling tower
- Low overall height (~ 75m)
- Plumes invisible most of the time

Integrated firing concept
- High efficiency
- High flexibility
- Security of supply / availability
- Biomass option

Halving of capacity and decommissioning of more than the same capacity
- Reduced emissions
- Reduced shading

BoAplus steam generators and the hybrid cooling tower will again be substantially reduced in height
Lignite can make important contributions to security of supply

In power generation and refining today:

- Lignite-fired power plants are as flexible as modern gas stations, which makes them an ideal partner to renewables
- Lignite-based refining products are used in private households and industry
- As a domestic raw material, lignite reduces Germany’s import dependence

As a carbon supplier in future:

- Raw material supply of the chemical industry is largely based on mineral oil and natural gas today
- Mineral oil reserves are becoming scarcer and their quality is declining
- Chemical industry can diversify its raw material base with lignite, with prices remaining stable over the long term

→ Rhenish lignite also offers options for replacing imported energy sources and for supplying the chemical industry with carbons in the long run