3rd ICEPE: CALL FOR PAPERS
Transition to Renewable Energy Systems
June 3 - 6, 2013
Frankfurt am Main/Germany

Mission
The 3rd ICEPE: Transition to Renewable Energy Systems serves as an international platform for a comprehensive review and the discussion of the present technological developments and latest research findings. The concept of the conference is to highlight Existing Game Changers and to look into Missing Links in order to achieve the G8 goals of reducing 80% of the CO₂ emission by 2050 and realize a major share of renewable energies by 2030.

On the first day of the conference delegates may expect the presentation of showcases from policies, studies and real projects under way. The second and third days are designed to bring out and discuss up-to-date technologies in detail. By providing cutting edge oral and poster presentations and comprehensive overviews this truly international and interdisciplinary event addresses decision makers and delegates from politics and the private sector, executives and researchers.

Parallel Sessions

- **Power Generation**
  - Onshore Wind Power
  - Offshore Wind Power
  - Power Production by Photovoltaics
  - Solar Thermal Power Production
  - Maritime Power Production
  - Hydropower
  - Geothermal Power Production
  - Future Role of Fossil Power Plants

- **Gas Production**
  - Chemical Gas Production
  - Electrochemical Gas Production
  - Photoelectrical Gas Production

- **Biomass and Biofuels**
  - Biomass – Global Aspects and Resources
  - Biomass for Power Production
  - Biofuels

- **Energy Storage**
  - Pumped Hydro Storage
  - Geological Gas Storage
  - Technical Gas Storage
  - Advanced Batteries

- **Energy Distribution**
  - Smart Grids
  - Power-to-Gas Technologies

- **End-use Technologies**
  - Sustainable Buildings - OECD
  - Sustainable Buildings - BRICS
  - Electromobility

- **Other**
  - Emerging and Developing Countries

Oral and poster contributions are welcome to all session topics. Please submit abstracts (≤ 200 words) via www.icepe2013.com until October 31, 2012

www.icepe2013.com

The book will be part of the conference proceedings.
09:00  Registration
10:00  Motivation for Transforming to Renewable Energy Systems  
Session Chair: Detlef Stolten, Juelich Research Center, Germany
10:00  Opening  
Detlef Stolten, Juelich Research Center, Germany
10:10  Welcome Address: BMBF  
Staatssekretär Georg Schütte, BMBF, Germany
10:25  The Way to make the Energy World Renewable  
Jeremy Rifkin, FOET, USA*
10:55  Transformation to Renewable Power  
Hermann Albers, Bundesverband WindEnergie e.V., Germany
11:10  Renewable Strategy in South Korea  
Changmo Sung, Green Technology Center-Korea, South Korea
11:25  Coffee Break
11:55  Transition to Renewables as a Challenge for the Industry  
Carsten Rolle, BDI, Germany
12:10  Industry Perspectives of Wind Power  
Henrik Siesdal, Siemens Wind Power A/S, Denmark
12:25  Challenges of Electric Drives prepared for the Transportation Sector  
Christian H. Mohrdieck, Daimler, Germany
12:40  A Utility’s View on the Transition to Renewables  
N.N.
12:55  Renewables as a Market Opportunity for an Independent Power Producer  
Bernd Bartels, BeBa Energie GmbH, Germany
13:10  Lunch and Poster Exhibition
14:10  The Energy Report – A Fully Sustainable Global Energy System by 2050  
Carsten Petersdorff, ECOFYS, Germany
14:35  Renewables for a Sustainable Energy Supply - Best Practice Worldwide  
Douglas Arent, NREL, USA*
15:00  An Innovation Strategy for DESERTEC with Incremental Steps  
Ulrich Hueck, DESERTEC Foundation, Germany
15:25  Technologies for Transition to a Sustainable Energy System in China  
Zhang Xiliang, Institute of Energy Environment and Economy, Tsinghua University, China
15:50  Scotland: Electricity Generation Policy  
Colin Imrie, The Scottish Government, Great Britain
16:15  Coffee Break
16:45  Hydrogen as an Enabler for Renewables  
Detlef Stolten, Bernd Emonts, Thomas Grube, Juelich Research Center, Germany
17:10  Era of Transition towards Renewable Energy Based Economy via Clean Production Processes for Power, Fuels and Commodities  
Nesrin Ozalp, Mechanical Engineering Program, Qatar
17:35  New Values with Renewables for Transportation  
Tae Won Lim, Hyundai Motor Company, Korea*
18:00  Japan’s Energy Policy after the 3.11 Natural and Nuclear Disaster – From a Viewpoint of the R&D of Renewable Energy and its Current State  
Hirohisa Uchida, Department of Nuclear Engineering, School of Engineering, Japan
18:25  Pre-investigation of Hydrogen Technologies at Large Scales for Electric Grid Load Balancing  
Fernando Gutierrez-Martin, Univ. Politècnica Madrid, Spain
18:50  Get together & Poster Exhibition
20:00  End of the Conference Day

Colour Code

<table>
<thead>
<tr>
<th>Plenary Section</th>
<th>Breaks</th>
<th>Keynotes</th>
<th>Power Production</th>
<th>Gas Production</th>
<th>Storage</th>
<th>Distribution</th>
<th>Application</th>
<th>Biomass</th>
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<tbody>
<tr>
<td></td>
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<td>Green</td>
<td>Red</td>
<td>Grey</td>
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<td>Brown</td>
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</table>

*invited
**Wednesday, June 5, 2013**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>09:00</td>
<td>The Transition to Renewable Energy Systems from an Ecological Perspective</td>
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<tr>
<td></td>
<td>Uwe Schneidewind, Wuppertal Institute, Germany</td>
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<tr>
<td>09:30</td>
<td>The Transition to Renewable Energy Systems from an Economical Perspective</td>
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<tr>
<td></td>
<td>Martin Grundmann, ARGE Netz, Germany</td>
</tr>
<tr>
<td>10:00</td>
<td>Energy Storage Technologies as Enabler for Renewable Energy Systems</td>
</tr>
<tr>
<td></td>
<td>Andreas Hauer, ZAE Bayern, Germany</td>
</tr>
<tr>
<td>10:30</td>
<td>Coffee Break and Change Rooms</td>
</tr>
<tr>
<td>11:00</td>
<td>Onshore Wind Power</td>
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<tr>
<td></td>
<td>Session Chair: Po Wen Cheng, University of Stuttgart, Germany</td>
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<tr>
<td></td>
<td>Biomass – Global Aspects &amp; Resources</td>
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<tr>
<td></td>
<td>Session Chair: Gustav Melin, Svebio, Sweden</td>
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<tr>
<td></td>
<td>Photoelectrical Gas Production</td>
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<td></td>
<td>Session Chair: John Turner, NREL, USA</td>
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<td></td>
<td>Pumped Hydro Storage</td>
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<td></td>
<td>Session Chair: Atle Harby, SINTEF, Norway</td>
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<tr>
<td>12:30</td>
<td>Lunch and Poster Exhibition</td>
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<tr>
<td>13:30</td>
<td>Natural Gas Pipeline Systems</td>
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<tr>
<td></td>
<td>Gerald Linke, E.ON Ruhrgas AG, Germany</td>
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<tr>
<td>14:00</td>
<td>Introduction to a Future Hydrogen Grid</td>
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<tr>
<td></td>
<td>Joan Ogden, University of CA Davis, USA</td>
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<tr>
<td>14:30</td>
<td>Power Production by Photovoltaics</td>
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<tr>
<td></td>
<td>Session Chair: Bernd Rech, HZB, Germany</td>
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<tr>
<td></td>
<td>Electrochemical Gas Production</td>
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<tr>
<td></td>
<td>Session Chair: Jürgen Mergel, Juelich Research Center, Germany</td>
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<tr>
<td></td>
<td>Power to Gas</td>
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<td></td>
<td>Session Chair: Detlef Stolten, Juelich Research Center, Germany</td>
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<tr>
<td></td>
<td>Biomass for Power Production</td>
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<td></td>
<td>Session Chair: Daniela Thrän, UFZ, Leipzig, Germany</td>
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<tr>
<td>16:00</td>
<td>Coffee Break</td>
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<tr>
<td>16:30</td>
<td>Solar Thermal Power Production</td>
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<tr>
<td></td>
<td>Session Chair: Robert Pitz-Paal, DLR, Germany</td>
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<tr>
<td></td>
<td>Geothermal Power</td>
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<td></td>
<td>Session Chair: Chris Bromley, GNS Science, New Zealand</td>
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<tr>
<td></td>
<td>Geologic Gas Storage</td>
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<td></td>
<td>Session Chair: David Evans, British Geological Survey, UK</td>
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<td></td>
<td>Emerging &amp; Developing Countries</td>
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<tr>
<td></td>
<td>Session Chair: Dieter Holm, ISES, South Africa</td>
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<tr>
<td>18:00</td>
<td>End of Conference Day</td>
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<tr>
<td>19:00</td>
<td>Reception</td>
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<tr>
<td>19:30</td>
<td>Conference Dinner</td>
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<tr>
<td>20:00</td>
<td>Dinner Speech (N.N.) and Poster Award</td>
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**Thursday, June 6, 2013**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Introduction to Transmission Grid Components</td>
</tr>
<tr>
<td></td>
<td>Armin Schnettler, RWTH Aachen, Germany</td>
</tr>
<tr>
<td>09:30</td>
<td>Introduction to the Transmission Networks</td>
</tr>
<tr>
<td></td>
<td>Göran Andersson, ETH Zürich, Switzerland</td>
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<tr>
<td>10:00</td>
<td>Potential and Technologies for Energy Savings in the Industrial Sector</td>
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<tr>
<td></td>
<td>Harald Bradke, Fraunhofer ISI, Germany</td>
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<tr>
<td>10:30</td>
<td>Coffee Break</td>
</tr>
<tr>
<td>11:00</td>
<td>Offshore Wind Power</td>
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<tr>
<td></td>
<td>Session Chair: David Infield, University of Strathclyde, UK</td>
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<td></td>
<td>The Future Role of Fossil Power Plants - Design and Implementation</td>
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<tr>
<td></td>
<td>Session Chair: Erlend Christensen, VGB Power Tech, Germany</td>
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<td></td>
<td>Smart Grid</td>
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<td></td>
<td>Session Chair: Goran Sirbac, Imperial College, UK</td>
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<td></td>
<td>Sustainable Buildings / Europe</td>
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<td></td>
<td>Session Chair: Karsten Voss, University of Wuppertal, Germany</td>
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<tr>
<td>12:30</td>
<td>Lunch and Poster Exhibition</td>
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<tr>
<td>13:30</td>
<td>Advanced Batteries</td>
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<td>Session Chair: N.N.</td>
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<td></td>
<td>Biofuels</td>
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<td></td>
<td>Session Chair: Franziska Müller-Langer, DBFZ, Germany</td>
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<td></td>
<td>Maritime Power Production</td>
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<td></td>
<td>Session Chair: David Krohn, RenewableUK, United Kingdom</td>
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<td></td>
<td>Sustainable Buildings / BRICS</td>
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<tr>
<td></td>
<td>Session Chair: Yan Da, Tsinghua University, China</td>
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<tr>
<td>15:00</td>
<td>Coffee Break</td>
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<tr>
<td>15:30</td>
<td>E-Mobility</td>
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<td>Session Chair: David L. Greene, Oak Ridge National Laboratory, USA</td>
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<td></td>
<td>Hydropower</td>
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<td></td>
<td>Session Chair: Arund Kilingheit, NTNU, Norway</td>
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<tr>
<td></td>
<td>Chemical Gas Production</td>
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<td></td>
<td>Session Chair: Christian Sattler, DLR, Germany</td>
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<td></td>
<td>Technical Gas Storage</td>
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<tr>
<td></td>
<td>Session Chair: Birgit Scheppat., Rhein-Main-Universität, Germany</td>
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<tr>
<td>17:00</td>
<td>Conclusion of the Conference</td>
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<td></td>
<td>Viktor Scherer, Ruhr Univ. Bochum, Germany</td>
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<tr>
<td>17:20</td>
<td>Closing Remarks</td>
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<td></td>
<td>Detlef Stolten, Juelich Research Center, Germany</td>
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<tr>
<td>17:30</td>
<td>End of the 3rd ICEPE</td>
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Hydrogen as an Enabler for Renewable Energy Systems

Detlef Stolten, Thomas Grube

Institute of Electrochemical Process Engineering
Forschungszentrum Jülich GmbH

5th EnergyDays
Eindhoven University of Technology
4th October 2012
Eindhoven
Future Energy Solutions need to be Existing Game Changers

**Drivers**
- Climate change
- Energy security
- Competitiveness
- Local emissions

**Grand Challenges**
- Renewable energy
- Electro mobility
- Efficient central power plants
- Fossil cogeneration

**Goals**
- Germany to reduce GHG emissions by 40% in 2020
- 55% in 2030
- 70% in 2040
- 80-95% in 2050 with reference to 1990
- Danish distributed electricity and heat is to be fossil free by 2035 (no nuclear in DK)

Timeline for CO$_2$-Reduction

2050 80% reduction goal fully achieved
2040 market penetration
2030 research finalized for 1st generation technology

Development period: unil 2040
Research period: until 2030 => 18 years left for research

Timelines für the 2040 and 2030 goals are even shorter
Research period for 2040 goal: 8 years left (- 70% CO$_2$)
Research period for 2030 goal: -2 years left (- 55% CO$_2$)
### GHG Emissions Shares per Sector in Germany

<table>
<thead>
<tr>
<th>Sector</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy sector</td>
<td>37%</td>
</tr>
<tr>
<td>Thereof power generation</td>
<td>32%</td>
</tr>
<tr>
<td>Transport (90% petroleum-based)</td>
<td>17%</td>
</tr>
<tr>
<td>Thereof passenger transport</td>
<td>11%</td>
</tr>
<tr>
<td>Thereof goods transport</td>
<td>6%</td>
</tr>
<tr>
<td>Residential</td>
<td>11%</td>
</tr>
<tr>
<td>Industry, trade and commerce</td>
<td>23%</td>
</tr>
<tr>
<td>Thereof industry</td>
<td>19%</td>
</tr>
<tr>
<td>Thereof trade and commerce</td>
<td>4%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>8%</td>
</tr>
<tr>
<td>Others</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

**Absolute amount as of 2010:** 920 m metric tons

2.2% of the GdP in DE spent for oil imports @ $80/ barrel

3% of the GdP in DE spent for all primary energy imports @ $80/ barrel @ 1.5 ct/kWh for coal @ 2.5 ct/kWh for NG

Source: Emission Trends for Germany since 1990, Trend Tables: Greenhouse Gas (GHG) Emissions in Equivalents, without CO₂ from Land Use, Land Use Change and Forestry, Umweltbundesamt 2011

Transport-related values: supplemented with *Shell LKW Studie – Fakten, Trends und Perspektiven im Straßengüterverkehr bis 2030*. 
Power Consumption per Capita has been Increasing

2012 until 2020:
Population -2%
Power/capita +0.7-1% p.a
(Reunification effect levelled)

Hence: Power consumption to increase by: + 5-7 %
## CO₂ Equivalent Factors of Green House Gases

<table>
<thead>
<tr>
<th>GHG(^1)</th>
<th>Equivalent Factors of GHG to CO₂ [1] for Three Timelines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 Years</td>
</tr>
<tr>
<td>CO₂</td>
<td>1</td>
</tr>
<tr>
<td>CH₄</td>
<td>72</td>
</tr>
<tr>
<td>N₂O</td>
<td>289</td>
</tr>
<tr>
<td>HFC(^2)</td>
<td>437 – 12 000</td>
</tr>
<tr>
<td>PFC(^2)</td>
<td>5 200 – 8 630</td>
</tr>
<tr>
<td>SF₆</td>
<td>16 300</td>
</tr>
</tbody>
</table>

### Average global radiative forcing \([W \ m^{-2}]\) of green house gases [1]

<table>
<thead>
<tr>
<th>GHG</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>1,66</td>
</tr>
<tr>
<td>CH₄</td>
<td>0,48</td>
</tr>
<tr>
<td>N₂O</td>
<td>0,16</td>
</tr>
<tr>
<td>Chlorinated-HCs</td>
<td>0,34</td>
</tr>
</tbody>
</table>

\(^1\) Selection of GHG according to [2]

\(^2\) Bandwidth according to systematics in [1]; HFC: flourinated Hydrocarbons; PFC: Perflourinated Carbons

Sources: [1] IPCC, 4th Assessment Report, Technical Summary, 2007, S. 32-33; literature usually refers to 100 years timeline
Institute of Electrochemical Process Engineering

Sources:
# Energy Density of Energy Carriers for Transportation

<table>
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<tr>
<th></th>
<th>Physical Storage Density</th>
<th>Technical Storage Density</th>
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<tbody>
<tr>
<td></td>
<td>[MJ l(^{-1})]</td>
<td>[MJ kg(^{-1})]</td>
</tr>
<tr>
<td>Gasoline</td>
<td>32</td>
<td>43</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>5 @ 700 bar</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li-Ion Batteries</td>
<td>1 – 1.8 ‡</td>
<td>0.4 - 0.7</td>
</tr>
<tr>
<td>Li – air Batteries</td>
<td>~ 40</td>
<td></td>
</tr>
</tbody>
</table>

- § Existing system by Opel / GM
- §§§ Fuel cell system considered
- ‡ 250 – 500 Wh/kg
- † Cooling cells and ΔSOC ≤ 50% considered
- # In early laboratory stage
Comparison of Different Propulsion Concepts or Vehicles

<table>
<thead>
<tr>
<th>Feature</th>
<th>ICV (Diesel)</th>
<th>ICV (Gasoline)</th>
<th>FCV</th>
<th>BEV</th>
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</thead>
<tbody>
<tr>
<td>Fuel consumption</td>
<td>✗</td>
<td>✗ ✗</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Cruising range</td>
<td>+ +</td>
<td>+</td>
<td>+</td>
<td>✗ ✗</td>
</tr>
<tr>
<td>Fueling time</td>
<td>+ ✗ ✗</td>
<td>+ ✗</td>
<td>+</td>
<td>✗</td>
</tr>
<tr>
<td>THG-Potential</td>
<td>✗</td>
<td>✗ ✗</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Noise emissions</td>
<td>✗ ✗</td>
<td>✗</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Particle emissions</td>
<td>✗ ✗ ✗</td>
<td>✗ ✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Safety</td>
<td>✗</td>
<td>✗</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Traffic flow</td>
<td>✗ ✗</td>
<td>✗ ✗</td>
<td>✗</td>
<td>✗</td>
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<tr>
<td>Infrastructure requirements</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>
Safety: Separation of the Oxidant from the Fuel

<table>
<thead>
<tr>
<th></th>
<th>Energy Density (MJ/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNT</td>
<td>7.4</td>
</tr>
<tr>
<td>Diesel</td>
<td>36</td>
</tr>
<tr>
<td>Chocolate</td>
<td>22</td>
</tr>
</tbody>
</table>

⇒ High energy densities pose no inherent risk

The intimate mixture of an oxidant with a fuel plus potential gas formation poses the risk

Vehicle battery w/ cruising range of 400 km (250 miles) is proposed to have
1500 Wh/kg = 5.4 MJ/kg
w/ $\rho \sim 2$ g/cm$^3$  ⇒ 10.8 MJ/l

Reactants of high energy batteries will inherently be close to each other in a μm or sub-μm distance
Hence, mechanical aspects and prevention of gas formation will be of utmost importance in the development

Hydrogen is stored in a separate containment protected from access of the oxidant
Concept for a Novel Energy System

1. Timeline requires focus on Existing Game Changers and Missing Links
2. Only renewables can deliver on the GHG reductions required
3. Only electromobility can deliver on the GHG requirements
4. Wind power, electrolysis, hydrogen and fuel cells for transportation are potential game changers
5. Renewables require dynamic bulk storage like geologic H₂ storage
6. Cost efficiency is paramount
Scenario of the Energy System for Germany in View of 55% CO₂ Reduction

Onshore Wind Power
Same number of wind mills as of end 2011 (22500 units)
Repowering from Ø 1.3 MW to 7.5 MW units => Σ 167 GW
Averaged nominal operating hours: 2000 p.a. ¹

70 GW (potential according to BMU 2011², Fino => 4000 h)

Offshore Wind Power

Photovoltaik
24.8 GW as status of 12/2011³, volatility considered

Other Renewables
Constant as of 2010⁴

Excess Energy
Water electrolysis \( \eta_{\text{LHV}} = 70 \% ^5; > 1000 \text{ operating hours} \\
\text{Pipeline transport + storage in salt caverns}

Transportation
Hydrogen for fuel cell cars: cruising range 14900 km/a⁶,
consumption 1kg/100km

Residential Sector
50% savings on natural gas as of 2010

Back-up Power
Open gas turbines; combined cycles > 700 operating hours/a
Part load considered by 15% reduction on nominal efficiency
Wind power curtailment

Electrolyze wind peaks

Use wind power directly and fill gaps with power from gas power plants
Results for Scenario of 55 % of CO₂ Savings

Total amount of electricity produced; includes electricity for hydrogen production 745 TWh

Transmitted electricity (vertical grid load) 488 TWh

Electricity for hydrogen production 257 TWh => 5.4 m tons H₂

Power sector:
All nuclear, coal, lignite and oil is substituted
Natural gas used for compensating fluctuations in Renewable energy

Electricity for hydrogen production in transportation:
28.5 m vehicles
2.1 m light duty vehicles
50,000 buses

Mix of vehicles according to the study German Hy
Other than in German Hy all vehicles are FC vehicles
GHG Emissions According to Scenario

- 2030 target is achieved. Further reductions are feasible.

Institute of Electrochemical Process Engineering
Energy Concept Study for Germany 2030

**Electricity Production** \(2010\): 628 TWh\(_{\text{gross}}\)

- Lignite: 23%
- Hard Coal: 19%
- Nuclear: 13%
- Natural Gas: 13%
- Wind: 6%
- Other RE: 7%
- Biomass: 5%
- PV: 2%
- Water: 3%

**Installed Power** \(2030\):
- 167 GW Onshore Wind
- 70 GW Offshore Wind
- 25 GW PV
- 6 GW other EE
- 65 GW Gas power

**Production** \(2030\): 744 TWh

- 256 TWh Electrolysis
- \(\text{H}_2\) Transport Sector

**GHG emissions, m t**
- Energy: 37%
- Electric.: 32%
- Transp.: 17%
- P. Cars: 11%
- Resid.: 11%
- Ind. & Com.: 23%
- Agric.: 8%

**Targets**
- -26% Energy
- -55% Electric.
- -70% Transp.
- -80% P. Cars

**Production**
- Electrolysis plants (84 GW)
- Gas power plants (42 GW)
- Caverns (150)
- Pipelines (43-59,000 km)
- Refueling Stations (9800)

**Investment, bn €**
- < 120 bn € w/o wind turbines & e-grid

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Hydrogen avoids more CO₂ in Road Transport than in Electric Re-conversion

Fuel consumption ratio ICE / FCEV 2,0

CO₂ emissions of substituted fuel in MJ gasoline / natural gas 1,25

CO₂ avoidance through H₂ utilization transport / re-conversion 2,5

**Constraints:**

**Re-conversion:** combined cycle PP after transport in NG pipelines, efficiency ~ NG CCPP

**Road transport:** replacement of (1) less efficient power trains & (2) more carbon-rich fuel
Daimler B-class F-Cell as an Example

• Small scale production started
• Delivery of 200 vehicles beginning of 2010

<table>
<thead>
<tr>
<th>Drive train</th>
<th>Electric motor with fuel cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net power (kW/PS)</td>
<td>100/136</td>
</tr>
<tr>
<td>Nominal torque (Nm)</td>
<td>290</td>
</tr>
<tr>
<td>Top speed (km/h)</td>
<td>170</td>
</tr>
<tr>
<td>Fuel consumption NEDC (l Diesel equivalent/100 km)</td>
<td>3,3</td>
</tr>
<tr>
<td>CO2 total (g/km min.–max.)</td>
<td>0,0</td>
</tr>
<tr>
<td>Cruising range (km) NEDC</td>
<td>385</td>
</tr>
<tr>
<td>Capacity/ power lithium ion battery (kWh/kW)</td>
<td>1,4 /35</td>
</tr>
<tr>
<td>Freeze start-up capability</td>
<td>Down to -25 °C</td>
</tr>
</tbody>
</table>

http://media.daimler.com/dcmedia/
Stuttgart 28.8.2009
Annual hydrogen production: 5.4 m tons

Transmission grid to German districts (Landkreise)
  • Length: 12,000 km
  • Investment: 6-7 bn €

Distribution to 9800 refueling stations w/ 1500 kg H₂/d
  • Length: 31-47,000 km
  • Investment: 13-19 bn €

2) incl. compressors for compensation of pressure losses
Hydrogen production: 5.4 million t/a
Max power over 1000 h: 84 GW
Storage capacity required at constant discharge:
- 0.8 m tons
- 9 bn scm
- 27 TWh\textsubscript{LHV}

Storage capacity for 60 day reserve_approx. 90 TWh

(Pumped Hydro Power in Germany: 0.04 TWh\textsubscript{e})

Existing NG-storage in Germany:
- 20.8 bn scm
  - thereof salt dome caverns:
    - 8.1 bn scm (in use)
    - 12.9 bn scm (in planning/construction phase)

=> Twice the existing storage capacity in salt domes needed
# Options for Bulk Storage of Fluctuating Renewable Energy

## Electrical Storage

<table>
<thead>
<tr>
<th>Storage Type</th>
<th>Energy Density</th>
<th>η&lt;sub&gt;Zykl&lt;/sub&gt;</th>
<th>ct/kWh*</th>
<th>τ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-Ionen batteries</td>
<td>0.7; 1.5</td>
<td>80-90%</td>
<td>12</td>
<td>Sec.</td>
</tr>
<tr>
<td>Na/S batteries</td>
<td>0.5 MJ/l</td>
<td>75%</td>
<td>8</td>
<td>Sec.</td>
</tr>
<tr>
<td>Lead acid batteries</td>
<td>0.3 MJ/l</td>
<td>80%</td>
<td>12</td>
<td>Sec.</td>
</tr>
<tr>
<td>Redox-flow batteries</td>
<td>0.3 MJ/l</td>
<td>75%</td>
<td>4</td>
<td>Sec.</td>
</tr>
</tbody>
</table>

## Mechanical Storage

<table>
<thead>
<tr>
<th>Storage Type</th>
<th>Energy Density</th>
<th>η&lt;sub&gt;Zykl&lt;/sub&gt;</th>
<th>ct/kWh*</th>
<th>τ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed air st. @ 100 bar</td>
<td>0.01 – 0.02 MJ/l</td>
<td>40%/70% adiabat</td>
<td>?/13</td>
<td>Min</td>
</tr>
<tr>
<td>Pumped hydro st. @ 100-700m</td>
<td>0.001 – 0.007 MJ/l</td>
<td>85-90%</td>
<td>2.5</td>
<td>Min.</td>
</tr>
<tr>
<td>Flywheels</td>
<td>0.2 MJ/l</td>
<td>k.A.</td>
<td>K.A.</td>
<td>Sec.</td>
</tr>
</tbody>
</table>

## Chemical Storage

<table>
<thead>
<tr>
<th>Storage Type</th>
<th>Energy Density</th>
<th>η&lt;sub&gt;Zykl&lt;/sub&gt;</th>
<th>ct/kWh*</th>
<th>τ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen @ Δp=100bar</td>
<td>1.0 MJ/l</td>
<td>98%/68%/41%</td>
<td>2.5/10/18</td>
<td>Months</td>
</tr>
<tr>
<td>Methane @ Δp=100bar</td>
<td>3.6 MJ/l</td>
<td>99%/55%/30%</td>
<td>1/ 11/24</td>
<td>Months</td>
</tr>
<tr>
<td>Gasoline</td>
<td>32 MJ/l</td>
<td>85%/25%</td>
<td>8/32</td>
<td>Months</td>
</tr>
</tbody>
</table>

* estimated numbers

## Geologic Storage

- Rock salt caverns
- Porous caverns
  - Aquifers
  - Oil and gas containing porous caverns

## Technical Storage

- Gas tanks
Options for Water Electrolysis

Alkaline electrolysis
Liquid electrolyte (KOH)
40–90°C

- Mature technology, ~10 years lifetime
- < 3.6 MW stacks / plants < 156 MW
- Ni catalysts
- Hydrogen for chemistry
- < 350 kW units dynamically operable
- MW units operated statically
- Shunt current required
- Cost \( \frac{\text{MW}}{\text{MW}} \) ~750 €/kW, \( \frac{\text{atm}}{\text{atm}} \) ~1000€/kW

PEM - electrolysis
Polymer electrolyte
20–100°C

- Niche markets / Development
- 1kW - 150 kW units; 5 commercial
- Pt and Ir as catalysts
- High potential for overload; \( f = 2-3 \)
- Simple plant design
- 500 $/kW (NREL)
- €1500@ 2015 (FZJ)
- € 600@ 2030 (FZJ)

High temperature electrolysis
Ceramic electrolyte
700–1000°C

- Laboratory stage
- kW stage
- Ni catalysts / perovskite catalysts
- High potential for overload
- Efficiency up 100%; thermoneutral
- Efficiency > 100% w/ hot steam
- Brittle ceramics, slow progress
- No dependable cost information

Institute of Electrochemical Process Engineering
Investment Cost for 55% CO$_2$-Reduction Scenario

**Stationar**

<table>
<thead>
<tr>
<th>Description</th>
<th>bn €</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water electrolyzers 84 GW @ 500 €/kW</td>
<td>42</td>
</tr>
<tr>
<td>Hydrogen pipeline grid</td>
<td>19 – 25</td>
</tr>
<tr>
<td>Gas caverns</td>
<td>5§ - 15&amp;</td>
</tr>
<tr>
<td>Fueling stations (Full supply of DE W/ 9800 units)</td>
<td>20</td>
</tr>
<tr>
<td>Additional NG-power plants</td>
<td>24</td>
</tr>
<tr>
<td>(42 GW GT + comb. Cycles, 23 GW already in place)</td>
<td></td>
</tr>
</tbody>
</table>

**Sub total stationary** | 110 – 126 |

**Vehicles**

<table>
<thead>
<tr>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell vehicles#:</td>
<td></td>
</tr>
<tr>
<td>28 m x 4,565 k€/ each extra cost:</td>
<td>128</td>
</tr>
</tbody>
</table>

**Total** | 238 - 254 |

§ compensating annual fluctuation
& strategic reserve for 60 days
# about the same additional cost for battery and hybrid drive trains
Cost consideration for Different Options for Making Use of Fluctuating Renewable Power

Current hydrogen price: 9.50 €/kg <=> 29 ct/kWh
Target price (cf. CEP): 6 €/kg <=> 18 ct/kWh
Infrastructure and the Chicken and Egg Problem

There is no such thing as an chicken and egg problem:
Evolution worked and it worked it out via precursor stages!

Positive example: US Highway act of 1956:

- 25 Mrd. US$, 66000 km Interstate Highways @ 90% subsidy
- Technology was developed, communication was in place,
  volume and impact of such an infrastructure was unprecedented

People who cannot image the future wanting to keep the status quo, hide behind it
Conclusions

- Wind power bears the potential to transform the German energy sector
- The proposed reduction potential of 55% is achievable; the timeline until 2030 is to be clarified
- Hydrogen as a means of energy storage is indispensable since
  - Methanation is economically not viable
  - Other means of storage like pumped hydro or batteries fail capacity-wise
- There is no such thing as surplus wind power; i.e. it is not for granted and should be used most economically in transportation
- Capital cost is manageable
- The \( \text{CO}_2 \) reduction measures draw on:
  - Power production: -20%
  - Transportation: -6.5%
  - Residential heating: -2.2%
- Further reduction potential through:
  - Biofuels as surrogates for liquid fuels
  - Energy conservation measures
  - Incorporation of contributions of other concepts like smart grids, heat pumps etc.
Thank You for Your Attention!

3rd ICEPE
Transition to Renewable Energy Systems
June 3-6, 2013
Frankfurt, Dechema Haus

Call for abstracts open until Oktober 31, 2012

www.icepe2013.com
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