FLEXIBLE DIMETHYL ETHER PRODUCTION FROM BIOMASS GASIFICATION WITH SORPTION ENHANCED PROCESSES

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DME and other renewable fuels for automotive

Among the different solutions for “greening” the automotive sector, DME has several advantages: it requires only moderate adjustments of vehicle and diesel motor and yields high efficiency and low emission.

Source: The Volvo group sustainability report 2014

Production processes and supply chain still require improvements to be competitive.
Recent facts on DME as vehicle fuel

- **USA, 2017**: Demonstration of DME as fuel in Mack Trucks vehicles owned by New York City Department of Sanitation (DSNY), as alternative to Diesel. The evaluation is taking place at the Fresh Kills Landfill on Staten Island, New York, with fuel-grade DME produced by Oberon Fuels.

- **China, 2015**: A consortium collaborating on a DME vehicle demonstration project has received certification from the provincial government of Shanghai for a DME fueled heavy-duty diesel engine satisfying Euro 6 emission standards. The engine, a modified 6 liter 135 kW WP6 common rail injection diesel engine from Weichai Power, is being demonstrated on short-haul heavy-duty street sweeper and refuse trucks.

- **Germany, 2015**: Ford Motor Company is leading a 3-year project co-funded by the German government to develop and test the world’s first production Mondeo passenger car to run on DME.

- **California, 2015**: The State of California approves DME’s use as a vehicle fuel, allowing the retail sale of DME throughout the state.

- **Geneva, 2015**: The International Organization for Standardization (ISO) published a specification for DME fuel, marking another important milestone in the introduction of DME as an ultra-low emission fuel for a range of automotive, power, and heating applications.

- **Sweden, 2010-13**: BioDME EU FP7 project ([www.biodme.eu/](http://www.biodme.eu/)) demonstrated DME production from black liquor gasification, its distribution and field test of 10 Volvo trucks fuelled by DME, which covered a total milage of more than 800 000 km. [http://www.biodme.eu/](http://www.biodme.eu/)

The FLEDGED project will deliver a process for Bio-based dimethyl Ether (DME) production from biomass gasification, validated in industrially relevant environment (TRL5).

**NOVEL FLEDGED PROCESS**

Flexible sorption enhanced gasification (SEG) process

Sorption enhanced DME synthesis (SEDMES) process

- Process intensification
- Efficiency improvements
- Environmental impact reduction
- Cost reductions
- Process flexibility

**FLEDGED process: SEG + SEDMES**

- **SEG process**
- **Tar/PM removal**
- **H₂S separation**
- **SE-DME synthesis**
- **DME separation**

Optional CO recycle (smaller for given yield)
Process intensification

**Biomass to DME with conventional process**

- Biomass
- Steam
- Air (if ind. gas)

Gasification process → Tar/PM removal → WGS unit → CO₂ separation → H₂S separation

ASU

H₂/CO/CO₂ recycle → MeOH synthesis → MeOH separation

MeOH recycle

DME synthesis → DME separation

**Biomass to DME by FLEDGED process**

- Biomass
- Steam
- Air

SEG process → Tar/PM removal → H₂S separation → SE-DME synthesis → DME separation

Optional CO recycle (smaller for given yield)

DME
Solid material with Ca-based sorbent is circulated between the gasifier-carbonator and the combustor-calciner to:

- produce a N$_2$-free syngas with no need of pure oxygen production and external heating of the reactor;
- absorb CO$_2$ in the gasifier and adjust C/H content in the syngas.
SEG process flexibility: tailored syngas module

By controlling the SEG process parameters (solid circulation, Ca/C ratio in the gasifier, gasifier temperature, S/C ratio), syngas composition can be adjusted to match with the downstream synthesis process.

Source: Martínez, Romano, 2016. Energy 113, 615-630.
SEG process flexibility: tailored syngas module

Influence of the gasification temperature on the syngas module ‘M’

Results shown on this slide were obtained in the project 30KB011C which has received funding within the program „Forschung und Entwicklung zur Optimierung der energetischen Biomassenutzung“ from the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety of Germany.
Sorption enhanced DME synthesis

Methanol synthesis:

\[
\text{CO} + 2\text{H}_2 \rightleftharpoons \text{CH}_3\text{OH}
\]

\[
\text{CO}_2 + 3\text{H}_2 \rightleftharpoons \text{CH}_3\text{OH} + \text{H}_2\text{O}
\]

Reverse water-gas shift (WGS)

\[
\text{H}_2 + \text{CO}_2 \rightleftharpoons \text{CO} + \text{H}_2\text{O}
\]

Methanol dehydration

\[
2\text{CH}_3\text{OH} \rightleftharpoons \text{CH}_3\text{OCH}_3 + \text{H}_2\text{O}
\]
Sorption enhanced DME synthesis

Equilibrium with in-situ water removal:

- Temperature: 275 °C
- Pressure: 25 bar(a)
- Composition: 54 mol% H₂, 15 mol% CO, 7.7 mol% CO₂

Graph showing the composition of DME, CH₃OH, CO, and CO₂ as a function of steam slip.
Sorption enhanced DME synthesis

In presence of a H₂O sorbent, the thermodynamic limitation of DME yield from methanol dehydration can be significantly reduced. DME yield in SEDMES process is insensitive to CO:CO₂ ratio in the syngas.

Conventional direct DME (thermodynamic calculation)

Sorption enhanced DME (experimental observation)

M = 2

<table>
<thead>
<tr>
<th>Feed</th>
<th>Product C-distribution [mol%]</th>
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<tbody>
<tr>
<td>H₂:CO₂=3:1</td>
<td>MethOH: CO: CO₂: DME = 90:10:0:0</td>
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<tr>
<td>H₂:CO=2:1</td>
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275°C, 25 bar

- Increased CO/CO₂ flexibility
- Increased DME yield
- Decreased CO₂ content
Process flexibility: integration with intermittent RES

If integrated with an electrolysis unit providing renewable hydrogen, SEG process parameters can be adjusted to produce syngas suitable for SEDMES process.

Contribution to electric grid stability by power-to-liquid
Possibility of CO$_2$ capture and storage by oxyfuel combustion in the SEG combustor.
Facilities for TRL5 demonstration

Flexible SEG process will be demonstrated in the 200 kW dual fluidized bed facility at IFK, University of Stuttgart.

SEDMES process will be demonstrated in multi column PSA rig at ECN.
Other experimental facilities for SEG development

75 kW CSIC-ICB bubbling fluidized bed gasifier

20 kW USTUTT dual fluidized bed facility
Other experimental facilities for SEDMES development

Facilities for testing and synthesis of SEDMES catalysts at CSIC-ICP

High throughput test-rig (Spider setup) and Single column PSA test-rig (SEWGS-1 setup) at ECN
The consortium

- Politecnico di Milano (POLIMI)
- Quintis
- University of Stuttgart (USTUTT)
- Sumitomo FW SFW
- Frames Renewable Energy Solutions B.V. (FRES)
- Ecohispanica (ECOH)
- Consejo Superior de Investigaciones Científicas (CSIC)
- L'Institut National de l'Environnement Industriel et des Risques (INERIS)
- Energy research Centre of the Netherlands (ECN)
- Universitàt Stuttgart
- Politecnico di Milano (POLIMI)
## Work Packages

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<td><strong>Project coordination</strong></td>
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| WP2 | **Component development**  
  - Fundamental research on gasification of different biomass types and different natural sorbents (CSIC, USTUTT)  
  - Fundamental research on sorption enhanced DME production (CSIC, ECN) | **CSIC**  
  **ECN**  
  **University of Stuttgart**  
  **IFK** |
| WP3 | **Process validation at TRL5**  
  - Identification of experimental parameters/matrices (POLIMI, USTUTT, ECN, CSIC)  
  - Sorption Enhanced Gasification validation under industrially relevant conditions (USTUTT, CSIC)  
  - Validation DME production under industrially relevant conditions (ECN, CSIC) | **ECN**  
  **University of Stuttgart**  
  **CSIC**  
  **POLITECNICO MILANO 1863** |
# Work Packages

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<td>• Process simulation and optimization of full-scale FLEDGED plants (POLIMI, FRES)</td>
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<td>• Modelling of SEG dual fluidized bed reactors (LUT, CSIC)</td>
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<td>• Modelling of DME reactor and synthesis process (ECN, POLIMI)</td>
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<td>• Economic analysis of full scale SEG+SEDMES plants (FRES, ECOH, SFW, POLIMI)</td>
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<td>• Scale up study of SEG process (SFW, LUT, USTUTT)</td>
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<td>• Scale up study of SEDMES unit (FRES, ECN, POLIMI)</td>
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<td>• Environmental Life Cycle Assessment (QUANTIS)</td>
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<td>• Process safety Analysis (INERIS)</td>
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<td>• Socio-Economic Analysis (INERIS)</td>
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<td>• Short-medium term commercial exploitation at small scale (ECOH, FRES, SFW)</td>
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<td>• Medium-long term commercial exploitation at large scale (FRES, SFW)</td>
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<td>• Commercial exploitation of the SEG and SEDMES sub-processes (SFW, FRES)</td>
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| WP8  | Dissemination and communication |
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