FutureGas – Modeling renewable gas options in future integrated energy systems

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DTU Management Engineering
Department of Management Engineering
Agenda

- FutureGas
- Modeling renewable gas
- Results
- Further modeling
The aim of the FutureGas project is twofold:

1) **In an energy system context to facilitate the integration of the gas system with the power system, the district heating system and the transportation sector taking into account possible synergies**

2) **To facilitate a cost-efficient uptake of renewable gases, hereby in the longer term substituting natural gas and fossil fuels**

Period: 2016-2020

www.futuregas.dk
FutureGas

Structure of the FutureGas project

WP4 Integrated energy systems analyses

- Biogas
- Syngas
- Hydrogen

WP1 Gas conditioning

WP2 Gas Quality in End-use

WP3 Gas for Transport

WP5 Advanced Mathematical Modelling

WP6 Markets and Regulation

WP7 Scenarios & Recommendations
## Integrating VRE: Flexibility options

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<th>Liquid fuels</th>
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Nordic energy mix in 2015

The Nordic energy mix in 2015

Data Source: IEA 2017
Gas consumption 2011-2050

Danish Energy Agency – Wind scenario: Future development of the Danish gas consumption.

- Overall use of gas is declining
- Use of gas for individual heating is phased-out by 2035
- Use of gas for transportation is increasing
- By 2050, gas is used in the transport-, industry- and power & heat sector

Source: Gasinfrastrukturen. Den fremtidige anvendelse af gasinfrastrukturen. (Danish Energy Agency)
FutureGas scenario framework
Integrated energy systems

Resources
- VRE electricity
- Bioenergy
- VRE Heat
- Natural gas

Conversion
- Electricity import/export
- Variable electricity
- Electricity and heat generation
- Solar thermal
- Heat storage
- Power to heat

District heating system

Demand
- EV
- Transport
- Residential
- Industry

Electricity system
Integrated energy systems

**Resources**
- Electricity import/export
- Variable electricity
- Electrity and heat generation
- Solar thermal
- VRE electricity
- Bioenergy
- VRE Heat
- Natural gas

**Conversion**
- Electricity system
- District heating system
- Heat storage
- Anaerobic digestion
- Thermal gasification
- Gas catalysis
- Gas systems (including local systems, transportation of methane, syngas, biogas and H2)

**Demand**
- EV
- Transport
- Residential
- Industry
- Gas storage
Integrated energy systems

Resources
- Electricity import/export
- VRE electricity
- Bioenergy
- VRE Heat
- Fossil fuels
- Natural gas

Conversion
- Variable electricity
- Electricity and heat generation
- Solar thermal
- Heat storage
- District heating system
- Power to heat
- Electrolysis
- Anerobic digestion
- Gas catalysis
- Thermal gasification

Demand
- Electricity storage
- Gas storage
- Liquid fuel for transport
- Transport
- Residential
- Industry
- EV
- HP
Modelling of renewable gas and liquid fuels in future integrated energy systems

Rasmus Bramstoft, Amalia Pizarro Alonso, Ida Græsted Jensen, Hans Ravn, Marie Münster
Methodology

**Balmorel**
Energy system optimization model covering the Nordic power and district heating sectors.

**OptiFlow**
Generalized spatiotemporal network optimization model which facilitates modelling of renewable gas and fuel production.

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**Balmorel**
- Electricity balance
- District heat balance
- Electricity and district heat demands

**OptiFlow**
- Gas and liquid fuel demands

**TIMES-DK**
- Background system

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Least-cost power and district heating system
Hourly district heating prices
Hourly electricity prices

Optimisation of RE gas and fuel production
Power and DH production from RE-gas
Excess heat from thermal gasification
Electricity consumption in electrolysis
Spatial resolution

**Spatial resolution in Balmorel and OptiFlow**

Energy system optimization model covering the Nordic power and district heating sectors. Optimizes (operation and investments in) generation, transmission and consumption of the power and district heating sectors.
Spatial resolution
Modelling of RE-gas and fuel in OptiFlow
Biogas modelling

Parameters
- Investment and O&M costs
- Efficiencies
- Emissions
- Energy demands (Space-time)
- Resource pot. (Space-time)
- Transportation costs

Restrictions
- Min/max ratio of input/output
- Ramping constraints

Variables
- Investments
- Operation
- Location
Resource potential

Manure potential: 38 mio. tons

Straw potential: 54 PJ
Transport of resources

Resources

Transportation of resources
## Scenarios

- Simulation year - 2050

<table>
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<td>H2</td>
<td>25</td>
<td>30</td>
<td>58</td>
<td>40</td>
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</table>
Cost of producing RE-gas

![Graph showing the cost of producing renewable gas (EUR/GJ) for various methods such as NG price, Biogas, Biogas_UP, Biogas_H2, Syngas, BioSNG, BioSNG_H2, and Electrolysis. The graph indicates the breakdown of costs into investment, O&M, fuel costs, and heat costs.]
Cost of producing RE liquid fuel
Energy flows – Base line - 2050

**Resources**
- Manure: 17.6
- Deep Litter: 6.4
- Food Waste: 3.6
- Nature Areas: 2.7
- Other: 5.0
- Straw: 28.9

**Conversion**
- AD: 64.2
- Methanation: 76.6
- Biogas Upgr: 6.5
- P2H: 95.7
- P2G: 36.6
- Power grid: 334.9
- Solar: 91.4
- Wind: 244.0

**Demand**
- Gas demand: 75.0
- DH grid: 170.2
- DH consumption: 143.7
- Losses: 34.5

Unit: PJ
Energy flows – SNG - 2050

Resources
- Manure: 11.5
- Deep Litter: 6.4
- Food Waste: 3.6
- Nature Areas: 2.7
- Other: 5.0
- Straw: 40.5
- Wood_Chips: 1.4

Conversion
- AD: 47.9
- Biogas Upgr: 42.3
- Methane synthesis: 39.7
- P2G: 29.6
- P2H: 95.5
- Power grid: 330.5

Demand
- Gas demand: 75.0
- DH grid: 169.2
- DH consumption: 143.7
- Losses: 45.7

Unit: PJ
Energy flows – BioJet - 2050

Resources
- Manure: 8.6
- Deep Litter: 6.4
- Food Waste: 2.4
- Nature Areas: 2.7
- Other: 5.0

Conversion
- AD: 25.1
- Biogas Upgr: 26.3
- BioJet: 57.7
- Biogasoline: 24.2
- Methanol synthesis: 19.0
- Electrofuel: 15.0

Demand
- Gas demand: 25.0
- Aviation demand: 57.7
- Biofuel export: 9.2
- Liquid RE-fuel demand: 30.0
- DH consumption: 143.7

Unit: PJ

Unit: PJ

Resources

Conversion

Demand
Renewable gas and liquid fuel production (PJ) 2050
Bioenergy resources - 2050
Differences in el and DH production between the base line scenario and the other simulated scenarios - 2050

[Graph showing differences in el and DH production between scenarios]
Biofuel and biogas production - 2050
Excess heat used in DH network - 2050
Conclusions

- The results from the co-simulation of OptiFlow and Balmorel represents the socio-economic optimal system, where investments and operations optimization is undertaken for the integrated energy system, taking into account the spatial and temporal system integration between the gas, electricity, and district heating systems.

- The results of this study show that biomass plays a key role in future Danish energy systems. In particular, transforming the transportation sector, to a renewable-based sector, requires high utilisation of the finite biomass resources.

- To efficiently utilise the limited biomass resource, hydrogen is used in the biofuel production and to a certain extent when biogas is upgraded through the methanation process.

- Biomass is utilised for biomethane or SNG production, which can be utilised in industrial processes, for heat production to the district heating network or for flexible peak-load electricity generation.

- Modelling bioenergy as an integrated part of the energy system, leads to potential system benefits:
  - Excess heat from biorefineries is used efficiently in the Danish district heating networks.
  - Flexible production of hydrogen which can help to balance the power system.

- The analysis show furthermore that the geographical allocation of resources has an impact on the results, which implies that a spatial representation of the resources is necessary when including bioenergy in energy systems modelling.
Further gas modelling

- Individual heating (Ida Græsted Jensen)
- Industry (Frauke Wiese)
- Gas grid (Rasmus Bramstoft)
- Regulation (Ida Græsted Jensen)
Individual heating

Individuel opvarmning i Balmorel
Balmorel-modellering af individuel opvarmning

- 2 områder i hvert prisområde i Danmark: en-familie huse og lejligheder
- 9 teknologigrupper (pt), f.eks. Gaskedel, gaskedel og solvarme, gaskedel og luft-til-vand varmepumpe
- Optimering af andel af total forbrug fra hver teknologigruppe
- Inkluderer en \textit{træghedsparameter} til at repræsentere (u)villighed til at skifte teknologi
Shares by technology group

Individuel opvarmning i Balmorel
Modellering af teknologigrupper

![Graph showing energy distribution by technology group](image-url)
Industry

Modellering af varmeudveksling i Balmorel

- From Electricity Grid
- From District Heat Grid
- Industrial CHP (self production)
- Industrial heating process
- Excess heat
- Flame for process
- Process Heating low temperature process
- Process Heating high temperature process
- Heat Pump
- Heat
- Electricity
- Fuels: gas, oil, Biomass, other
- To DH
- Excess heat
## Industry

### Industri i Balmorel

### Clustering af slutforsbrug på varmeniveau

<table>
<thead>
<tr>
<th>Slutforsbrug</th>
<th>Temperaturniveau [°C]</th>
<th>Model varmetype</th>
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<tbody>
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<td>Rumopvarmning</td>
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<td>Destillation</td>
<td>50-100</td>
<td>PHL</td>
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<td>Opvarmning/kogning</td>
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<td>PHL</td>
</tr>
<tr>
<td>Tørring</td>
<td>omkring 100</td>
<td>PHL</td>
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<td>Inddampning</td>
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<td>Brænding/sintring</td>
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<td>PHH</td>
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Technologies

Industri i Balmorel

Tekniske muligheder

Teknologier:

• NG kedel
• El-kedel
• Fjernvarme+varmepumpe

Minimum metan brug:

• 17%\(^1\) af forbruget skal være gas med naturgaskvalitet for PHL og PHH områder
• Kan leveres af:
  • Opgraderet biogas (enten metanisering eller vandskrubber)
  • Termisk forgasnings gas (enten metanisering eller water-gas shift)
Preliminary results

Industri i Balmorel
Foreløbige resultater
Modelling the gas grid
Modelling the gas grid
Conceptual model

Scenarios and modelling the gas grid

Table 2: Relevant Danish energy system analysis tool characteristics. Based on (Connelly et al., 2010) but modifications are applied.

<table>
<thead>
<tr>
<th>Model type</th>
<th>Geographical area</th>
<th>Time resolution</th>
<th>Electricity</th>
<th>Heat</th>
<th>Transport</th>
<th>Industry</th>
<th>Detailed representation of gas network</th>
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Integrated energy systems

Resources
- VRE electricity
- Bioenergy
- VRE Heat
- Fossil fuels
- Natural gas

Conversion
- Electricity import/export
- Electricity storage
- Variable electricity
- Power to heat
- Electrolysis
- Heating and heat generation
- Solar thermal
- Heat storage
- Anerobic digestion
- Gas catalysis
- Thermal gasification
- Gas systems (including local systems, transportation of methane, syngas, biogas and H2)
- RE fuels
- Gas storage
- Liquid fuel for transport

Demand
- Transport
- Residential
- Industry
- EV
- HP
Local RE-gas grids

Principles for interaction between local RE gas grids (biogas, synthetic gas, H2) and the overall gas grid

Source: Energy Concept 2030 (Energinet.dk)
Modelling set up
Modelling of gas systems

Model - simplifications
- Non-linear equations
- Technical constraints
- Linepack
- Physical flows

Model as storage?
Ramping rates?
## Modelling setup

<table>
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<tr>
<th>Model Purpose</th>
<th>Inspiration from Energinet</th>
<th>Technical modelling</th>
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<tr>
<td>OptiFlow-Balmorel</td>
<td>Overall and simplified modelling of gas production and consumption</td>
<td>Gams model</td>
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<tr>
<td>Production and consumption: a line between areas, storage and a storage simulating linepack,</td>
<td>Simulating pressure, gas flows, linepack, gas storages, using a complex set of equations</td>
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<td>Results</td>
<td>Overall results, which allow assessments of the future role of the gas infrastructure in Denmark</td>
<td>Giving technical insight in the gas infrastructure to evaluate future challenges</td>
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More topics...

- White Paper on sector coupling
- Global sensitivities (together with Yi-kuang and Torjus)
- Model calculation time reductions (linked to BEAM-ME)
- Modeling storage (E.g. Case study of electrical storage in Austria or seasonal heat storage in DK)
ETIP SNET White Paper on Sector Coupling

1. INTRO - WHY SECTOR COUPLING?
2. STORAGE OVERVIEW
   2.1 THERMAL
   2.2 ELECTRICAL
   2.3 GAS/FUEL...
3. POWER TO HEATING AND COOLING (PTH/C)
   3.1 INTRODUCTION
   3.2 PTH IN INDIVIDUAL RESIDENTIAL BUILDINGS
   3.3 PTH IN INDUSTRY
   3.4 PTH FOR DISTRICT HEATING
   3.5 PTC
4. POWER TO ELECTRIC VEHICLES
   4.1 INTRODUCTION
5. POWER TO GAS/FUELS
   5.1 INTRODUCTION
6. CONCLUSIONS AND RECOMMENDATIONS
   6.1 INTRODUCTION
System Gas Modelling Energy Modelling Energy Future Gas