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FutureGas

The integration of gas in the future Danish energy system

by **Poul Erik Morthorst, Marie Münster, Tara Sabbagh Amirkhizi and Rasmus Bramstoft**

The FutureGas project assesses the arising question of the future role of gas in an effective, cost-efficient and sustainable transition of the Danish energy system. The project includes all major stakeholders of the Danish gas industry, and addresses all main aspects of the gas value chain in the integrated energy system. FutureGas will provide future pathways for the Danish energy transition towards a sustainable future, with a detailed representation of the gas system as an integrated part of the future energy system.

1. GAS IN THE DANISH ENERGY SYSTEM

Gas is a key energy carrier in the Danish energy system, accounting for 2 0% of the national energy consumption. Gas is widely used in the power, heating, industry, residential, and transport sectors, enabling sector coupling and interactions between different energy subsystems. The Danish gas grid transports approximately 4 billion Nm^3 of natural gas, of which almost 2.5 billion Nm^3 is consumed in Denmark.

The Danish government established the Danish gas grid in the 1980s to exploit the North Sea reserves of natural gas and to protect the Danish economy from the negative consequences of the international energy crisis. Therefore, Denmark has a mature gas infrastructure, which is an integrated part of the European gas system. The natural gas reserves in the North Sea are the primary source for gas in Denmark. However, the resources in the North Sea are estimated to be depleted in around 2040.

The gas infrastructure and utilisation of gas is a key part of the overall Danish energy system. Gas is used in industrial processes, to generate electricity in peak load situations, and in the transport sector. With a 40% share of wind energy in the danish power consumption, the requirements for flexibility in the energy system are increasing. Gas can be produced flexibly from renewable resources or electricity and can therefore offer a flexible energy resource.

The main question emerging today regarding the Danish gas sector is which role gas and the gas infrastructure will have in the future Danish energy system and how it can be optimally integrated in the overall energy system. This question is still open and needs to be evaluated.

2. THE STATE OF RENEWABLE GASES IN DENMARK

The Danish Energy agreement of 2012 is aiming to establish a fossil free economy in Denmark by 2050. This agreement, in addition to the climate act, has emphasis on the development of renewable gas resources as a part of the Danish energy agenda [1]. During the last years, the Danish energy policies have set a strong focus on biogas. Biogas production offers an efficient treatment and utilisation of manure and other organic waste products for energy production and soil improvement. Therefore the Danish government has set an objective to have 50% of the Danish manure utilised for renewable energy production by 2020 [2].

In 2015, around 1% of the Danish primary energy production originated from biogas, of which around 1000 TJ was upgraded and injected into the Danish gas grid. This share is still very small compared to natural gas (approx. 173510 TJ), which makes up to around one fourth of the Danish primary energy production [3]. With the current biogas support scheme, the production and upgrading of biogas has turned into an attractive business opportunity for Danish biogas plant owners. Since 2014, upgraded biogas injected to the Danish gas grid has been subsidized by a feed-in premium [4]. Hydrogen on the other hand is currently lacking sufficient infrastructure and economic feasibility to reach market maturity [5, 6]. The same applies to syngas production from thermal gasification [7].

3. THE FUTUREGAS PROJECT

The FutureGas project is a project supported by the innovation fund Denmark with a number of national and international partners from research and gas industry **(Figure 1)**. The project will run from 2016–2020.
The project aims to:

- 1) Facilitate the integration of the gas system with the heat and power system and the transport sector,
- 2) Enable a cost-efficient uptake of renewable gases in order to substitute natural gas and other fossil fuels in the long run.

The major part of the research concentrates on addressing the gas supply side such as conditioning of RE gases and the operation of the gas grid in combination with the demand side (CHP, industry and transport), developing the gas dimension in advanced system modelling, and, finally, on identifying the required policy and market structures for a successful implementation.

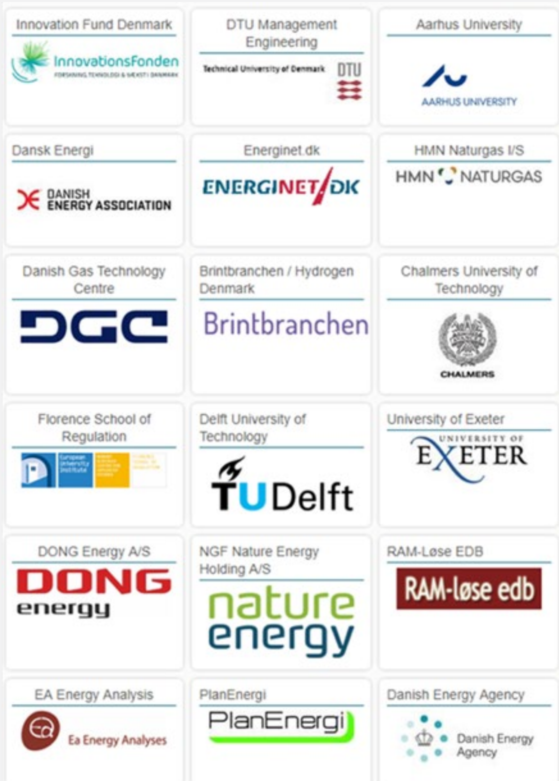

Figure 1: Partners in the FutureGas project

4. APPROACH

The project consists of seven work packages, each investigating variable aspects of the gas system. This way, the project captures the entire gas value chain in the energy system **(Figure 2)**. The work packages work closely together and deliver input to each other. This shows the truly interdisciplinary nature of the FutureGas project.

The project uses several technological and system related cases to demonstrate the current framework conditions for sector coupling and to demonstrate new framework conditions in the gas market. An example of a case is biogas upgrading (methanation). The methanation process connects the power grid to the gas grid by using hydrogen produced by a power-to-gas plant, which uses power from the grid to upgrade biogas. The upgraded biogas (biomethane) is then injected to the national gas grid.

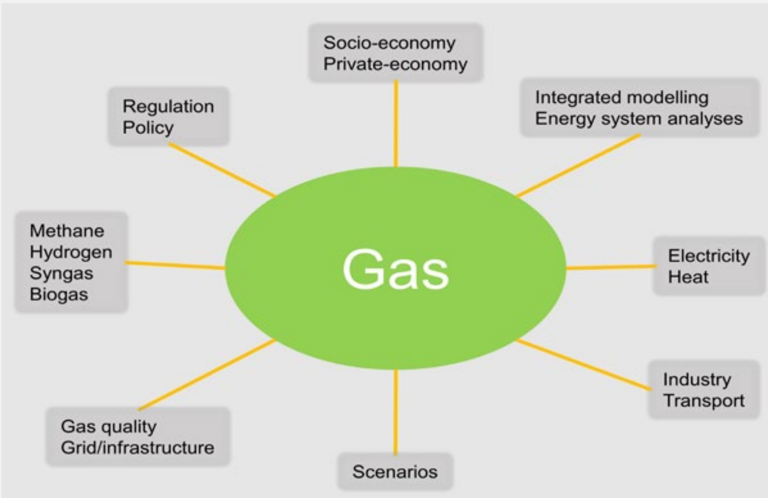

Figure 2: The scope of the FutureGas project

4.1 Work packages

The methodological flow of the FutureGas project is as shown in **Figure 3**. The starting point is the definition of a number of renewable gases (biogas, syngas and hydrogen). These can either be conditioned to a higher gas quality (e.g. to the Danish natural gas quality) or be utilised directly depending on the end-user requirements, e.g. in industry and transport. The work packages (WP's) of the FutureGas project are as following:

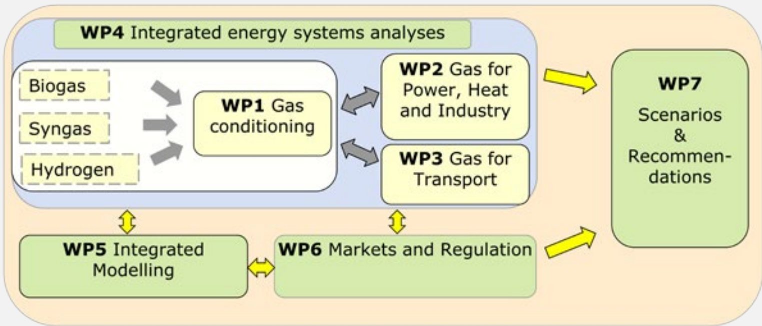

Figure 3: Methodological flow of the FutureGas project

WP 1: Gas Conditioning and grid operation

In this WP, the researchers will perform an analysis of existing and emerging technologies for biogas upgrading and syngas methanation. The work package investigates new and unconventional, especially in relation to how these can be conditioned for the existing gas infrastructure, addressing challenges such as cost efficient methanation and upgrading to natural gas quality.

WP 2: Quality requirements for end-use

WP2 establishes an extended and detailed picture of Danish gas utilisation paths. The aim is to identify which gas qualities are the most suitable for the new gases. The WP will cover renewable gases both with scenarios of injection into the natural gas grid and dedicated grids. For example, the work package evaluates if a grid mixed with natural gas, biomethane and biogas would be technically feasible from the end user perspective.

WP 3: Gas for transport

WP3 will assess the possible use of gas in transport in Denmark and its impacts. As an example, the WP will evaluate the utilisation of liquefied biomethane in marine transport and compressed biomethane in road transport.

WP4: Gas in the integrated energy system

In WP4, the role of gas – including renewable gases – will be modeled as a part of the integrated energy system, emphasizing the interactions and synergies between gas system and the power, heat, and transport sectors. In the example of biogas upgrading, the model uses the Danish market conditions as input, including regulatory tools that are applicable to biogas upgrading plants. It will further analyse how these market conditions will affect the scale of biogas upgrading in the future. This WP will be described further in the next section.

WP 5: Advanced mathematical modelling

In WP5 complex mathematical problems connected to modelling of large integrated systems will be analysed and the work from WP5 will act as a support function to WP4 by developing solutions to handle the large numbers of variables and equations imposed in large energy system models.

WP 6: Markets and regulation

WP 6 provides the market design and regulatory tools used as an input for work package 4. Regulatory tools, such as taxes, tariffs and subsidies are a deciding factor whether a technology will develop further in the long term or not. For example, when the Danish state introduced the subsidy for biogas in upgrading plants and CHP, the biogas production and the number of upgrading plants increased in Denmark.

WP 7: Future scenarios and Recommendations

Based on these future scenarios and the outcome of WP6 on markets and regulation and WP4 on integrated modelling, this WP will make recommendations including both business opportunities for industrial partners and for society. Developing joint scenarios in the project will furthermore contribute to the creation of a common mental platform, collaboration towards the same goals and communicating results to a broader audience.

5. A CONCEPTUAL MODEL OF THE GAS SYSTEM

The future Danish energy system is expected to have stronger couplings and interactions between energy subsystems [8], [9]. Therefore, to assess the green transition of the Danish energy system, a holistic energy system perspective is necessary [10]. Nonetheless, there are research gaps for methods and tools that facilitate modelling of integrated energy systems [11], [12].

A central part of the FutureGas project is the further development of the energy system optimisation model "Balmorel" to comprise a detailed representation of the gas system; hence allowing integrated assessments of the energy system including the power, district heating, gas, and transport systems. Therefore, a conceptual model of the gas system as an integrated part of the future energy system is developed **(Figure 4)**. The conceptual model ensures that essential elements of the gas system are modelled with sufficient detail to allow appropriate assessments of future interactions between the energy subsystems. This model highlights important elements, parameters, variables, necessary restrictions and propose modelling techniques to comprise these in the energy system model.

In particular, the modelling of the future gas system will include important technical aspects such as production of renewable gas, production of renewable fuels using renewable gas as input, conditioning (guided by work package 1), transmission, short-term storage (linepack), and seasonal storage. The model will also include consumption patterns, trade, as well as regulatory frameworks and market designs (provided by work package 6). After implementing the model in Balmorel, the model will encompass a detailed representation of the energy systems; gas, power, and district heating, while the transport and industry sectors are represented partially through exogenously defined energy demands. The industry demand will be provided by work package 2,

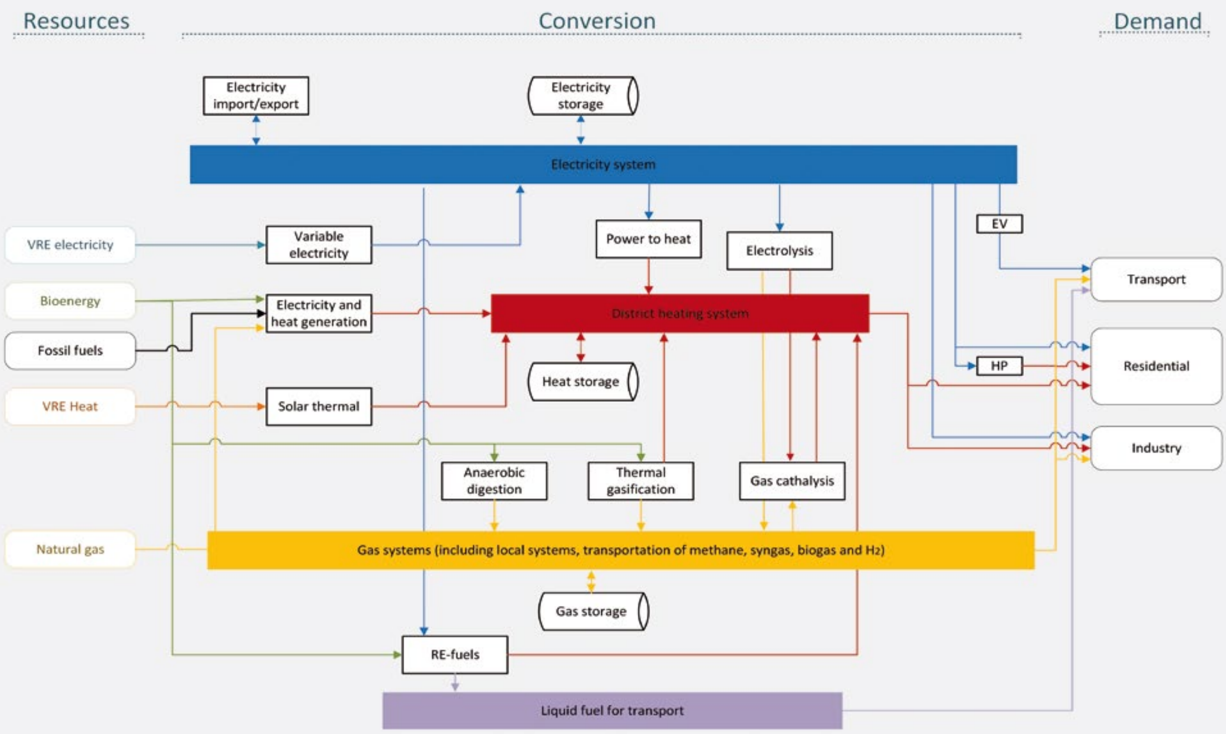

Figure 4: Modelling framework of the integrated energy system in the FutureGas project

while the transport demand will be provided by work package 3, and will be an outcome from TIMES energy system modelling.

Renewable gas production and renewable fuels for the transport sector is modelled in the generalized network optimisation model OptiFLow, which is hard-linked to Balmorel. In case of biogas upgrading (methanation) the electricity prices generated in Balmorel are used as input parameters in the OptiFlow modelling, while generated biomethane in OptiFlow can be used in energy technologies in Balmorel.

The FutureGas modelling framework will fill the research gap and improve the current state of modelling integrated energy systems by combining the above-mentioned features with:

1) Investment and operation optimisation,
2) High geographic resolution,
3) High temporal resolution,
4) Possibility of performing unit commitment optimisation,
5) Decommissioning of existing plants.

This framework allows modelling of future pathways towards sustainable energy systems with high shares of renewable energy sources, with a detailed representation of the gas system as an integrated part of the future energy system. In this way, assessments of a cost-efficient uptake of renewable gases and the flexibility of gas in terms of production, consumption, storages and import/export, can be facilitated. Thus, the modelling framework can help to answer the research questions stated in Section 3, and facilitate assessments of the role of gas in the future Danish energy system.

6. THE VALUE OF THE FUTUREGAS PROJECT (CONCLUSION)

The development of the gas system is important to investigate given the long-term energy policy targets, combined with declining gas consumption, and limited natural gas resources in the North Sea. Especially the new role of gas as a sector-coupling element will gain increasing importance in the future.

The FutureGas project investigates the crucial question of the future role of gas and the gas system in an effective, cost-efficient and sustainable energy transition of the Danish energy system. The FutureGas project includes all main aspects of the gas value chain in the energy system and will be used to provide insights to future energy trends, supporting stakeholders and policymakers in the strategic decisions for the Danish transition towards a sustainable future.

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