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TNO report

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Contents

1 Introduction

The BOF2UREA project aims to contribute towards the reduction of the impact on the climate of industrial activity through the production of urea from the energy and carbon in residual gases in integrated steel plants, using process- and cost-efficient technologies, while simultaneously delivering storage ready CO_2 at no extra costs. The proposed block diagram for this process is shown in Figure 1. This is enabled by the innovative Sorption-Enhanced Water-Gas Shift (SEWGS) technology [1] [2].

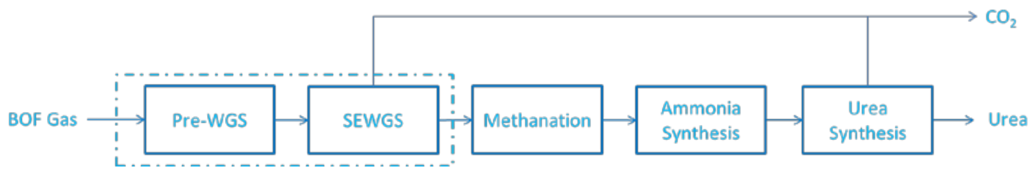

Figure 1. BOF2UREA Block Diagram

The one year project aimed to:
1. Optimise a process to produce urea from basic oxygen furnace gas at a cost level lower than that based on natural gas
2. Determine the CO_2 footprint reduction potential of commercial scale urea plant integrated with a steel plant
3. Form a lasting value chain to enable implementation within 5 year after conclusion of the project.

This final report provides a summary of the results from each of these objectives. Specifically, Chapters 2, 3 and 4 addresses objectives 1, 2 and 3 respectively.

1.1 Reference Case and Base Case

The comparison of BOF2UREA is done against a reference plant. The reference plant considered here is the combination of the use of BOF in a conventional steel plant and the production of urea from natural gas. The reference plant is shown in Figure 2. This is compared against the BOF2UREA configuration as shown in Figure 3. Note that since the use of BFG and COG do not vary, the operation of the steel plant Is considered out of scope.

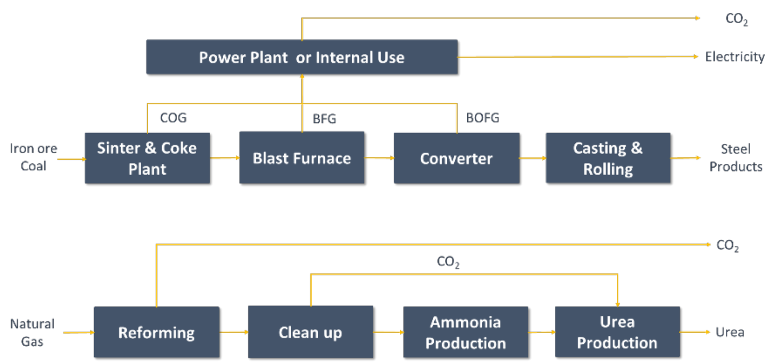

Figure 2. Reference Plant

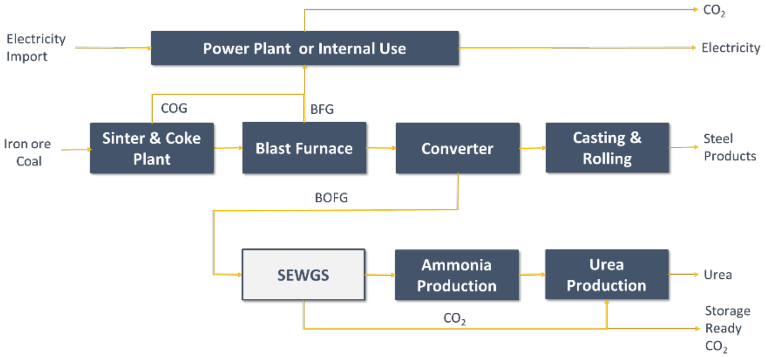

Figure 3. BOF2UREA Plant

2 Process Design and Costing

The BOF2UREA plant is subdivided into 4 sections. A front end section consisting of BOF gas compression, pre-Water Gas Shift (Pre-WGS), Sorption Enhanced Water Gas Shift (SEWGS), CO_2 heat recovery and compression and H_2 heat recovery. An interfacing section that cleans up trace elements poisonous to the downstream catalysts, compresses and adjusts H_2:N_2 of the H_2 stream. An ammonia production section compresses feed gas to a higher pressure, produces ammonia and separates the produced ammonia from the unreacted gases. And finally, a urea production section that combines ammonia and CO_2 to produce urea. Each of these sections are modelled using ASPEN Plus for units operating at steady state and MATLAB for the unit (SEWGS) operating at cyclic steady state. The overall flowsheet for the BOF2UREA plant is shown in Figure 5

2.1 Design Challenges

From an operational perspective, the largest challenges are related to large variation of BOF gas composition and the risk of BOF gas flow failure due to changing mode of operation at the steel plant. The design is done in such a way to minimize the impact of these challenges

The compositional variation coming out of the BOF buffer vessel is shown in Figure 4. The process design showed that the composition variations can be partly absorbed by the thermal inertia of SEWGS and control system can be designed to adapt to the remaining change. A key element in the future demonstration will be the validation of this damping and the effectiveness of simple control system to cope with these variations.

The failure of BOF can be handled initially by turning down capacity of downstream systems to consume BOF at a lower rate from the buffer vessel but for longer failures by switching to an alternate gas, i.e. Blast Furnace gas.

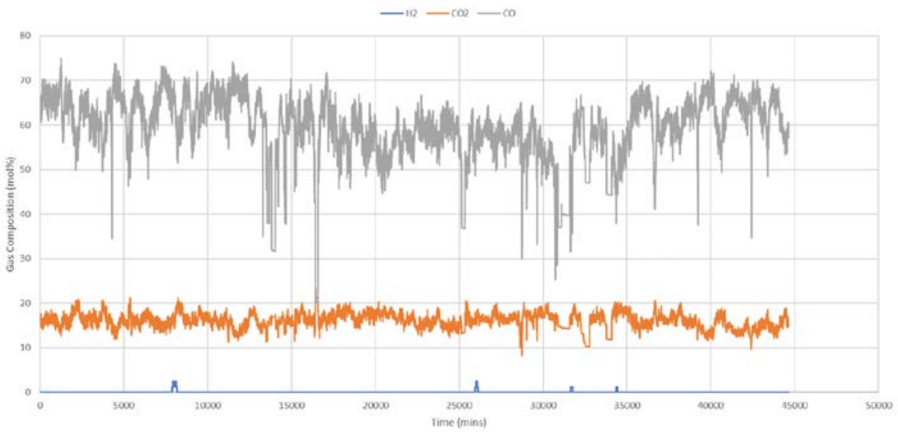

Figure 4. BOF Gas Composition Exiting Gas Holder over a period of one month

2.2 Process Description and Costing

The BOF gas first goes through dedusting to remove any dust which is detrimental to the moving parts in the compressors. Then it is compressed with a multistage compressor to the operating condition of the gas conditioning step, taken to be 24 bar in this case. The gas is then heated and mixed with steam before being fed to the pre-Water-Gas-Shift reactors. The exit of the pre-WGS is fed to the SEWGS. Here, any remaining CO is converted to CO_2 and H_2. The CO_2 is also removed from the gas phase. The exiting H_2/N_2 mixture proceeds towards H_2S and CO_X (trace) removal step. The CO_2 that is removed from the gas phase is released from the SEWGS in a regeneration steps. 20% of this CO_2 is cooled and compressed to the pressure necessary for urea synthesis, while the remaining 80% is compressed to a level necessary for CO_2 Storage.

Once the H_2/N_2 and mixture is purified to remove sulphur and oxygen containing compounds (these species are poisonous for the NH_3 catalysts), the mixture if fed to the NH_3 Loop. Where, depending on the ratio of H_2/N_2, a different yield of ammonia is achieved. A lower ratio will result in a lower yield, down to a limit below which the reaction will not proceed. The exiting ammonia is cooled to a liquid form and sent to storage. The ammonia is taken from the buffer storage and compressed to 300 bar for the urea synthesis, where it is mixed with the CO_2 from the gas conditioning step.

In terms of overall consumption rates, it takes 3.3 ton of BOF to produce 1 ton of urea while also producing 2.85 tons of storage ready CO_2. In addition, 1652 kWh of electricity is required to replace the electricity that would have been produced from 3.3 tons of BOF. From an energy and heat management perspective the plant can recuperate heat to a large extent, beyond which heat import from the steel mill and combustion of off gases is used to meet the remaining demand.

The total plant cost is estimated to be 120 M€ with an OPEX of 5 M€ per year (excluding feedstock cost).

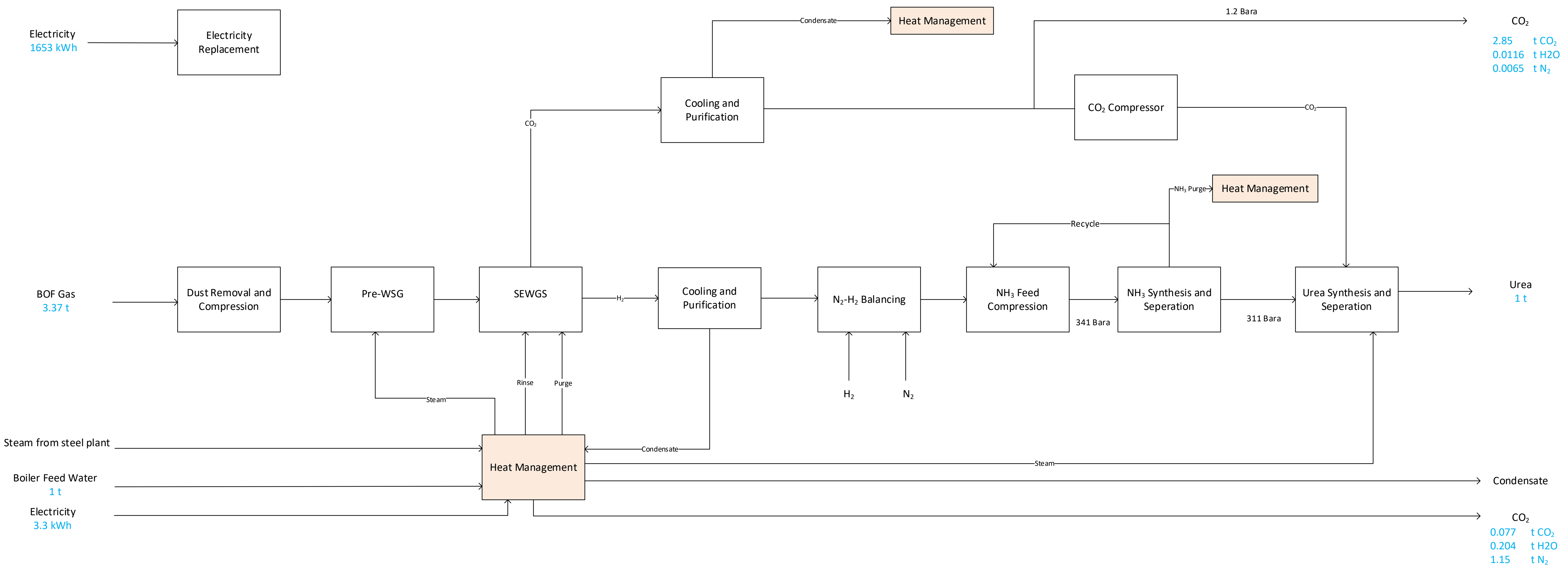

Figure 5. Process Flow Diagram for BOF2UREA

3 Life Cycle Assessment

A life cycle assessment has been carried out to assess the environmental impact of using BOFG for various applications. Each application is compared against it's counterfactual. In order to ensure that the comparison is accurate and uses realistic data the process design outcomes are used as input for the life cycle assessment. Multiple working sessions were used to align the process design with the LCA.

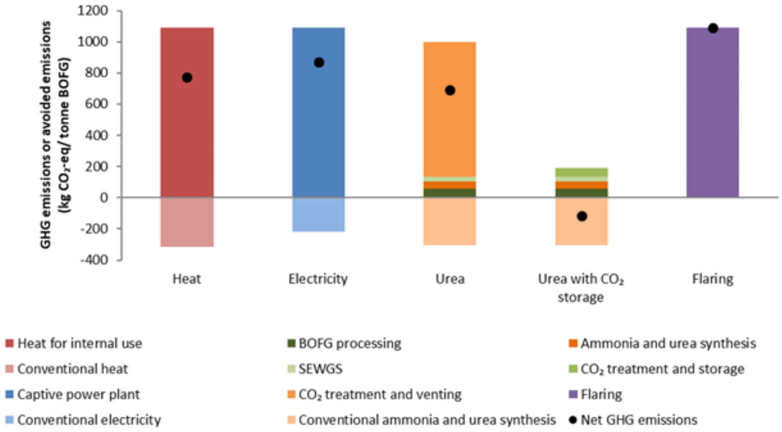

Figure 6. Life Cycle Assessment Result BOF2UREA

The results of the assessment is shown in Figure 6. The positive value indicate the emission of BOF for the stated application and the negative value indicate the emission from the counterfactual used for the exact same application. The black data points indicate the difference between the two. A net positive difference means there is no CO_2 reduction and a negative difference means there is a CO_2 reduction potential. As can be seen the use of BOF for heat and electricity are generate a significant amount of CO_2 emissions while the use of urea and storing the excess, capture ready CO_2 can reduce the emissions by 40%.

4 Commercial Implementation Plan

The commercial implementation plan is structured using TECOP to cover all necessary elements for successful deployment of the technology within 5 year after completion of the project. The items covered are shown in the table below. The scope of this report is the commercial implementation plan.

Category	Content
Technical	Definition of final product, scale, battery limits, location and timeline for scale up
Economic	Identify costs of scaling up, explore options for financing (e.g. EIB funding)
Commercial	Identify potential market changes (Steel and Urea) and engage end user
Organisational	Develop plan for licensing schemes and understand the business perspective of other partners
Political	Perform stakeholder mapping to identify key players

Technically The flow sheeting and process design efforts undertaken as part of WP1 are used to provide input for this section. Urea derivatives are selected as product due to their high value and low CAPEX production methods. Two possible locations with BOF availability and strong urea demand have been identified. Within the project it was identified that to commercialise the concept within the intended 5 years, the next step should be a TRL7 demonstration of conversion of BOF Gas to Urea. Efforts are currently ongoing to secure funding for a TRL7 demonstration of the key elements in the process line up.

Economic The economic analysis was done based on costing undertaken as part of WP1. The result of the analysis showed that it is possible to achieve an project IRR (Internal Rate of Return) of 9.5% (assuming 60% debt, the IRR on equity will be even higher). The cost drivers are the CAPEX of the plant and the feedstock costs. Note, a key outcome is that the CO_2 Tax (ETS) does not factor into the positive economic outcome. The financing of the next step (i.e. TRL7) demonstration will be through H2020 subsidy with contribution from industry.

Commercial The market for urea demand is expected to be strong in the foreseeable future due to the wide range of applications possible, including to aid reduction of NOx emission (with GWP 30 times that of CO_2) from cars and power plant. The market for Iron and Steel is strongly influenced by population growth, economic development, social behaviour, political regulation, technology development and geography. The development and implementation of carbon correction at borders and new technology developments should be monitored closely.

Organisational & Political The stakeholder mapping has identified the need for stronger involvement of the general public and trade associations in order to ensure the success of the project. The next phase of the project should take these into consideration.

5 Conclusions & Recommendation

5.1 Conclusion

The conclusion on technical feasibility, economic viability and environmental friendliness are:

Technical From the output of the project it is concluded there are no showstoppers for the production of urea from BOF gas using SEWGS. However, specific challenges have been identified for further validation during the next steps.

Economic From the output of the project it is concluded that the concept is economically viable under current market conditions without taking into account the effect of ETS price. Potential sites with BOF availability and urea market have been identified.

Environmental From the output of the project it is concluded that the concept provides an overall CO_2 benefit of 40% when compared to contrafactual of producing urea from natural gas.

5.2 Recommendation

The recommendations from the project are to pursue a next step where a TRL7 demonstration can take place and to further develop the sites identified for the first of a kind plant. The demonstrator should pay particular attention to:

1) How the dynamics in composition propagate through the system and their effect on performance of the capture system and ammonia synthesis loop.
2) Develop strategies for handling variations and switching to BFG when the BOF supply is not available.

Signature

Petten, 25 May 2020

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Dissemination

- Jebin James, Kiane de Kleijne, Marija Saric, Jurriaan Boon ‘BOF2UREA: A step towards CO_2 neutral steel & urea’. Presented at TCCS10, the 10th Trondheim Conference on CO_2 Capture, Transport and Storage. 17-19 June, 2019.
- Soledad van Eijk, ‘BOF2UREA - CO_2 capture in the iron and steel industry and subsequent utilisation of CO2 in urea’. Presentation of BOF2UREA concept during CCU Innovation Fund hosted by CO_2 Value Europe in Brussels, 19 September 2019.
- Soledad van Eijk, ‘BOF2UREA, say what?’ Presented at CO_2 Smart Use Congress, Rotterdam, The Netherlands,
- Kiane de Kleijne, Jebin James, Rosalie van Zelm ‘Environmental life cycle assessment comparison between urea produced from Basic Oxygen Furnace gas and natural gas’ Presented at Life Cycle Management – 9th International Conference, Poznan, Poland, September 2019.
- Jebin James ‘BOF to UREA’ To be presented at the 14th Stamicarbon Symposium, postponed to October 2020.
- Kiane de Kleijne, Jebin James, Steef V. Hanssen, Rosalie van Zelm ‘Environmental benefits of urea production from basic oxygen furnace gas’. Presented at Society of Environmental Toxicology and Chemistry (SETAC, online). 2020.
- Kiane de Kleijne, Jebin James, Steef V. Hanssen, Rosalie van Zelm, ‘Environmental benefits of urea production from basic oxygen furnace gas’ Journal of Applied Energy, accepted. 2020.

Acknowledgements

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