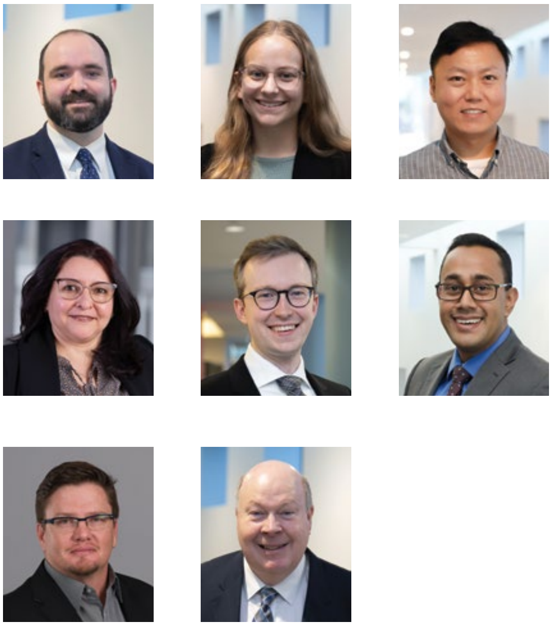
Methanation — An Opportunity to Recycle Carbon and More Efficiently Introduce Hydrogen to the Blast Furnace?



Steel producer interest in blast furnace hydrogen injection to reduce coke rates and carbon-related emission intensity has grown. Injecting hydrogen into the blast furnace has some inherent challenges, including limited utilization and heat balance difficulties. Injecting methane, by contrast, is a well-understood and practiced technology. Methanation of carbon-containing steel plant offgases presents an opportunity to use hydrogen in the blast furnace in an indirect fashion. In addition to reducing natural gas purchases, methanation has the added benefit of allowing carbon in the offgas to be recycled back to the blast furnace, rather than being emitted. This article explores the use of synthetic natural gas produced from offgas as a blast furnace fuel.

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Introduction

Steelmaking is an emission-intensive industry and is identified as a hard-to-abate industry sector regarding greenhouse gas emissions. Steel is critical to support global industrialization, economic growth and quality of life improvements, and the energy transition. Global demand is projected to increase to 2.7 billion metric tons per year by 2050[1] from production of 1.9 billion metric tons in 2023.[2] This presents a challenge as the industry aims to reach net-zero emissions by 2050. To accomplish this goal, an important milestone to achieve a 30% absolute emissions reduction by 2030 has been identified to be on the right trajectory to reach net zero 20 years later.[3] Integrated blast furnace and basic oxygen furnace (BF-BOF) steelmaking makes up 72% of global steel production and has the highest average carbon emission intensity of 2.3 metric tons of carbon dioxide (CO_2) per metric ton of crude steel (CS) produced. The incumbent BF-BOF assets with their high productivity suggest that BF-BOF steelmaking will be a significant portion of the steelmaking asset base for the foreseeable future. Therefore, it is imperative to find and implement process improvements to reduce the emission intensity of steel produced from BF-BOF facilities. In these facilities, the BF is the largest emitter, responsible for approximately 75% of most integrated steel mill emissions accounted for in the final steel product; and therefore, is an essential area for emission reduction initiatives.

There is growing interest in injecting hydrogen (H_2) through BF tuyeres as an alternative reductant to reduce the carbon intensity of steel made through the BF-BOF route. Hydrogen injection has promise, as it does not require major modifications to the core BF asset — only a change to injection lances and mild operating changes to maintain stable process conditions.

That said, hydrogen injection has some challenges and limitations that must be solved prior to widescale adoption. A major limitation is the high specific heat capacity of hydrogen, which demands a large amount of energy to heat the injected hydrogen to raceway conditions, negatively impacting the raceway adiabatic flame temperature (RAFT). Hydrogen is expensive and with the BF having a hydrogen utilization in the range of only 42–48%, about half of the injected hydrogen will exit in the blast furnace gas (BFG) without doing any chemical reduction work. Although hydrogen in the BFG can be combusted as a heating fuel elsewhere in the steel works, industry professionals note that this is a suboptimal use of an expensive fuel. Other challenges include the ability to safely handle and store hydrogen due to hydrogen's small molecular size, the potential for hydrogen embrittlement of existing steel components, and its explosion potential, especially near the expensive BF asset.

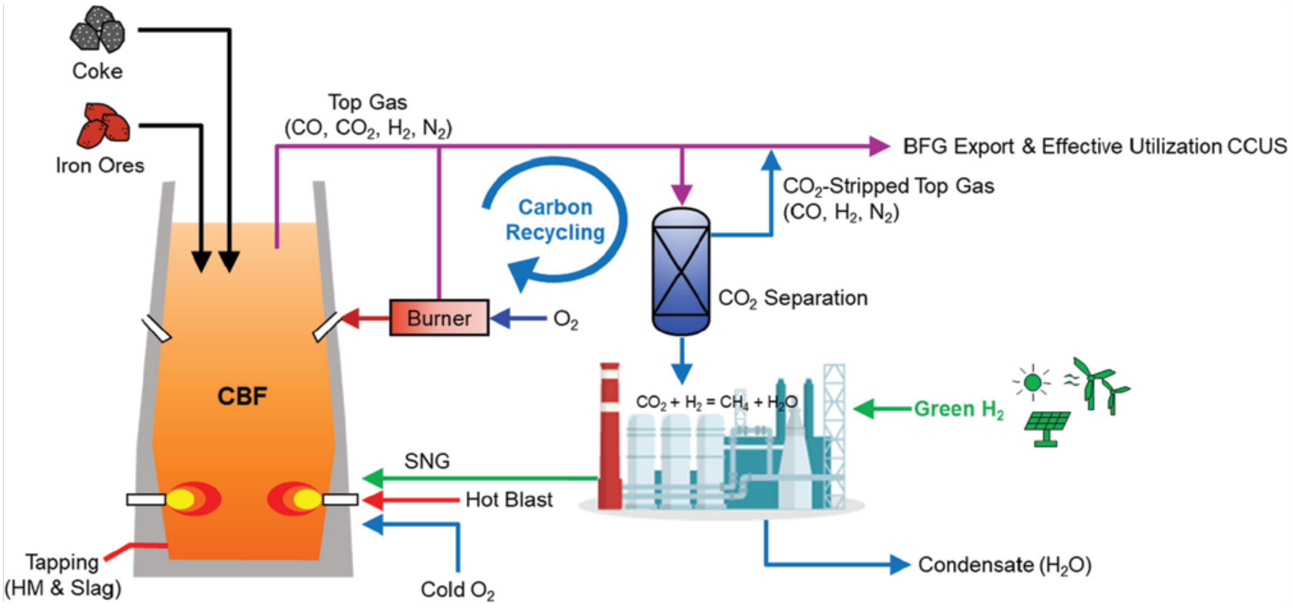
Methanation could help overcome the challenges associated with direct hydrogen injection, while still providing an emission reduction in BF ironmaking operations. It involves the hydrogenation of carbon monoxide (CO) and/or carbon dioxide (CO_2) to form methane (CH_4) and water vapor. Water can then be removed, producing synthetic natural gas (SNG) suitable for BF injection. The steel industry, especially in North America, has decades of experience injecting natural gas into BFs, and it is considered a mature technology. Methanating carbon monoxide and carbon dioxide present in various steel plant offgases may be a more efficient way of introducing hydrogen to the BF as an alternative reductant while allowing for carbon to be recycled within the steel works.

For regions where natural gas is expensive or unavailable, initial work has been done evaluating methanation-based processes for ironmaking. Japan's JFE is developing a novel process that integrates its "carbon recycling technology" into BF ironmaking.[4,5] In this process, the clean BFG is first treated in a carbon dioxide scrubber, and the separated carbon dioxide is then methanated using green hydrogen. By injecting the synthetic methane back to the BF, carbon dioxide is recycled, thereby avoiding its emission. For this reason, JFE refers to the synthetic methane as carbon-neutral (CN) methane. The BF can operate as either conventional BF or oxygen BF (OBF), in which hot blast air is replaced with cold pure oxygen. The theoretical calculations carried out by JFE's researchers indicate a reduction of up to ~30% in carbon dioxide emissions when the process is deployed on an OBF. The configuration nominated by JFE can be seen in Fig. 1. To validate this novel process, JFE is planning to construct a pilot-scale BF (150 m^3) in their East Japan Works and start the trial operations in 2025. A similar process is also examined by Perpinan.[6]

This article explores several flowsheets that incorporate methanation and SNG injection and compares them to a typical BF with natural gas and hydrogen injection practices. This was done to evaluate if methanation could

Figure 1

Schematic of JFE's carbon recycling blast furnace configuration for an oxygen blast furnace, reproduced from Reference 4.



be a more efficient use of hydrogen for emission reduction in BF operations.

When comparing top gas recycling combined with methanation to previously studied top gas recycling configurations, methanation has some advantages. The most developed top gas recycling process is the top gas recycling oxygen blast furnace (TGR-OBF) evaluated in the Ultra-Low Carbon Dioxide Steelmaking (ULCOS) program by the European Union.[7] The TGR-OBF configuration separates the carbon dioxide from the BF top gas then preheats and reinjects the hot CO-rich gas stream into the furnace at both the tuyere level and through a new set of stack tuyeres. An OBF arrangement is favorable as it enables a high recycling rate of top gas and maximizes the pulverized coal injection (PCI) rate. In addition, shifting to an OBF reduces the nitrogen (N_2) load in the BF and can lower the nitrogen removal and separation demands. This changes the heat balance significantly, as there is no nitrogen to carry the sensible heat to the furnace top. To ensure sufficient heat in the upper stack to dry raw material and prevent moisture from condensing (i.e., top gas temperature >110°C), a second set of tuyeres could be installed on the BF stack to inject hot reducing gases.

When top gas is recirculated, a route to remove nitrogen is needed to avoid accumulation in the blast furnace. Separating nitrogen from carbon monoxide is technically challenging due to similar molecular weights. Methanating the carbon monoxide allows nitrogen to be separated from the resulting methane in a dedicated unit operation. This allows for a wider range of hot blast nitrogen levels that can help with the heat balance challenges when hot blast air is replaced with pure oxygen and may avoid the need to implement a second set of stack tuyeres to increase top gas temperature above the dewpoint.

Overview of the Steel Industry's Carbon Dioxide Emission Intensity

To understand the carbon dioxide emission intensity of the BF-BOF steelmaking value chain, data published by the World Steel Association (worldsteel) was analyzed.[8] The performance of BF-BOF operations can be grouped into three categories, as described below, and shown in Fig. 2:

- Best-in-Class Producers. These are the steel producers with access to high-grade iron ore pellets, low-ash coal or natural gas, and advanced technologies resulting in an emission intensity of <2.0 t CO_2/t steel.
- Median Producers. This represents a large group of steel producers that have an emissions intensity between 2.0 and 2.5 t CO_2/t steel. A variety of efficiency improvements can allow this group to migrate toward the Best-in-Class producers' performance in the short to medium term.
- High-Emission Producers. These producers face major challenges or systemic disadvantages resulting in an emissions intensity >2.5 t CO_2/t steel. Transformational, long-term changes are likely needed to substantially reduce CO_2 emissions from this group.

To quantify the impact of alternative fuel gases, such as direct hydrogen injection or methanation and recirculation of offgases, the same methodology was used as in a previous article published by the authors.[9] The methodology accounts for the emission intensity of the entire integrated steelmaking value chain, including the upstream emissions from agglomeration, cokemaking, BF ironmaking, BOF steelmaking, and the related downstream emissions for casting and hot and cold rolling. In Fig. 2, publicly available information for several reference steel companies were overlaid on the worldsteel data. The reporting methodology for these reference companies are opaque; and therefore, the reported emission intensities were taken at face value.[9]

While the BF is the largest source of direct emissions in the value chain and the main area being evaluated in this article, the impact of changes in the BF on the other process areas should be considered. The best available techniques (BAT) reference document prepared by the European Commission[10] and a report on ironmaking in Western Europe[11] were used to establish the emission intensity of the various parts of the value chain, summarized in Table 1. While these benchmarks are 10 years old, they are the latest comprehensive benchmarking data available.[9]

Figure 2

Carbon dioxide emission intensity profile for global steel producers. Reproduced from data published by worldsteel, with publicly available reference steel mills from North America (NA), Russia (RU), India (IN) and Japan (JA), reproduced from Reference 9.

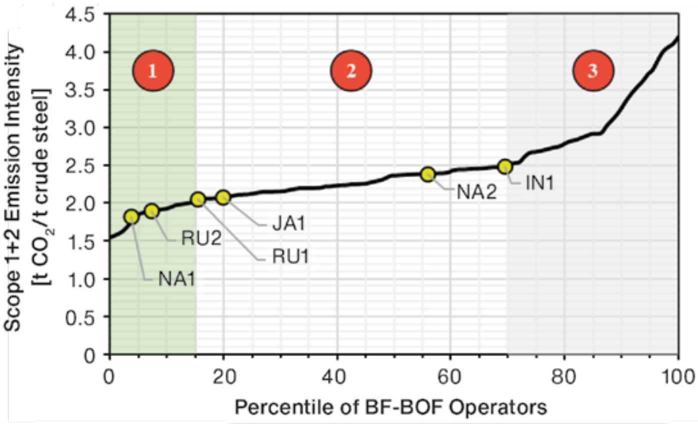


Table 1

Industry Benchmarks for Carbon Dioxide Emission Intensity in the BF-BOF Value Chain[9–11]

Percentile	Pelletizing [kg CO_2/t pellet]	Sintering [kg CO_2/t sinter]	Cokemaking [kg CO_2/t coke]	Ironmaking [kg CO_2/t hot metal]	Steelmaking [kg CO_2/t CS]*
10th	35	191	330	1,475	108
50th	105	251	441	1,630	140
90th	175	350	605	1,914	172

*CS = Crude steel as defined by World Steel Association: Steel in the first solid state after melting, suitable for further processing or for sale. Synonymous with raw steel.

Methanation Overview and Opportunity

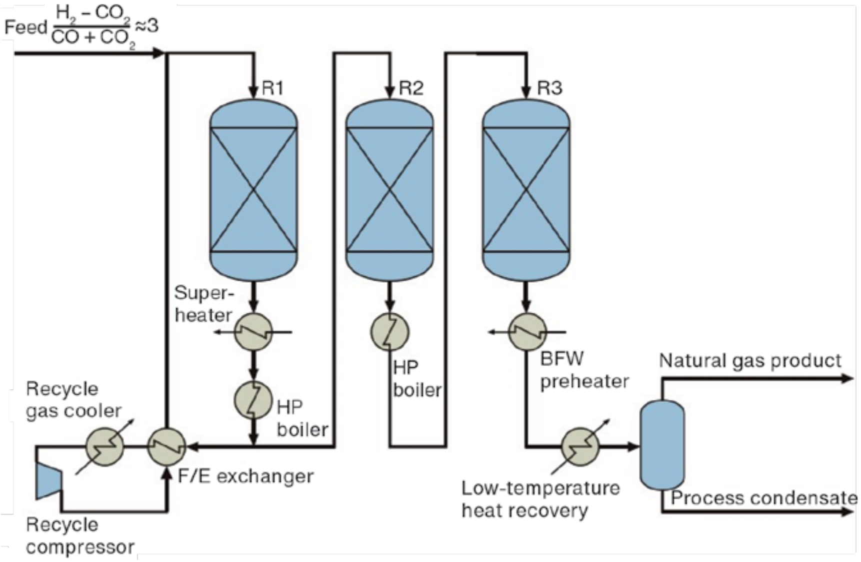
The top gas emitted from a conventional BF contains by volume about 22–25% carbon monoxide, 20–22% carbon dioxide, small amounts of hydrogen and water vapor, and the remainder of 40–50% nitrogen. This top gas is typically used as a combustion fuel in the BF stoves and power plant in an integrated steel mill. The contained carbon monoxide and carbon dioxide can be hydrogenated using methanation process technology to both recirculate carbon and introduce hydrogen to the BF, thereby reducing the amount of virgin carbon needed.

Several technology licensors offer the methanation process to produce SNG, including Linde, Topsøe, Johnson, Matthey and Air Liquide. The Topsøe Recycle Energy-Efficient Methanation Process (TREMP™) was considered in this study,[12] since information from public domain was available and sufficient to estimate SNG yields at this preliminary stage. The TREMP process includes three fixed-bed methanation reactors with an internal recycle and intermediate coolers for heat integration to produce SNG by converting hydrogen and carbon monoxide and dioxide into methane. It is important to note that a three-stage methanation process provides higher carbon dioxide/monoxide conversion; however, for the case where lower conversion rates are adequate, one to two stages can be considered. As methanation is a highly exothermic process, the TREMP technology recovers up to 85% of the energy as high-pressure superheated steam to offset energy requirements for compression.[12] While product compositions can vary with the TREMP technology, the base assumption used in this article is a production of SNG with approximately 75 mol% methane, which can be increased up to 94–98 vol. % methane by removing water and nitrogen downstream of the methanation unit. An example of the three-stage TREMP methanation unit configuration can be seen in Fig. 3.

As methane is a common and well-understood BF injectant, methanation could provide an opportunity to reduce both coke consumption and carbon dioxide emissions using top gas recycling. This allows green hydrogen to be introduced into the BF in a well-understood fashion, with SNG acting as a hydrogen carrier.

Figure 3

Example of the three-stage Topsøe TREMP™ technology, from Reference 12.



Base Case Scenario

The base case is a BF archetype that represents North American BFs that use natural gas as an injected fuel. The BF operation was modeled using a modified two-stage heat and mass balance.[13] Fig. 4 illustrates the two-stage balance for a standard BF configuration and Table 2 outlines the base case model operating parameters.

To translate the calculated emissions from the BF to the total associated emissions for the steelmaking value chain up to crude steel, the 50th percentile emission intensity for the upstream and downstream processes was assumed, as outlined in Table 1.

This base case allows for a comparison of the emission impacts of injecting hydrogen directly to the BF and injecting SNG produced from recycled top gas. This scenario is already a Best-in-Class Producer configuration from an emission intensity perspective, as described in Fig. 2. There are two main strategic advantages inherent to the base case. Firstly, the injected natural gas contains 25% by mass hydrogen, resulting in an emission reduction compared to PCI. Secondly, the use of 100% pellets (105 kg CO_2/t pellet) as the ferrous burden is an advantage from an emission intensity perspective compared to sinter (251 kg CO_2/t sinter). This leads to the base case emission intensity for the modeled integrated steel mill being 1,770 kg CO_2/t CS, which is at the 5th percentile of global integrated steel producers per Fig. 2.

This base case was chosen, as explored in a previous article,[9] to represent a more efficient BF-BOF steelmaking asset that will be critical for meeting the emission targets for the steel industry. The global fleet of BFs will be utilized for the foreseeable future, so finding ways to produce steel with a lower emission intensity in a stepwise fashion using existing assets will be needed to reach industry emission reduction targets.[9] Being more efficient, from both a raw material choice and equipment technology viewpoint, is a good pathway for producers in the Median Producer category to reduce their emissions in the short term to be on par with the Best-in-Class Producers. That said, once operating in the top 15th percentile, a more

Figure 4

Two-stage blast furnace heat and mass balance concept used to assess the scenarios.[13]

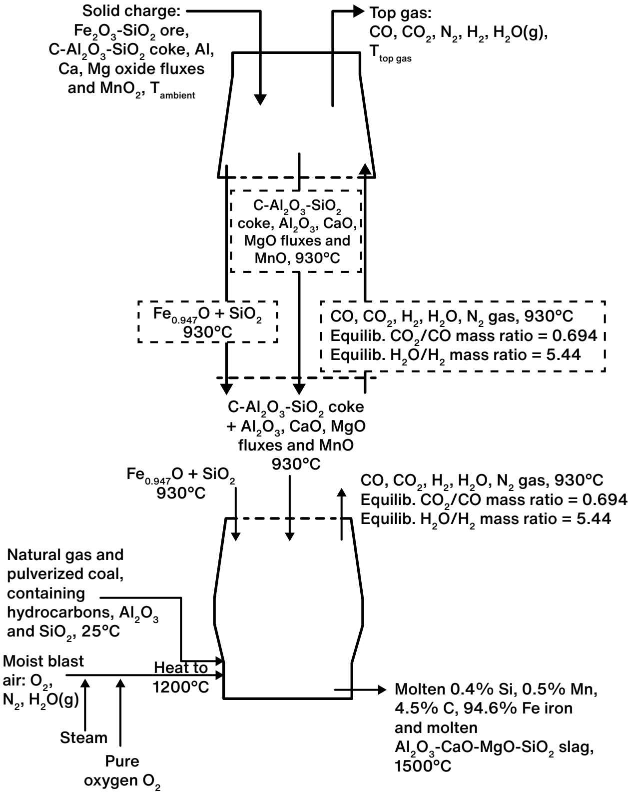


Table 2

Base Case Scenario of North American BF Injecting Natural Gas

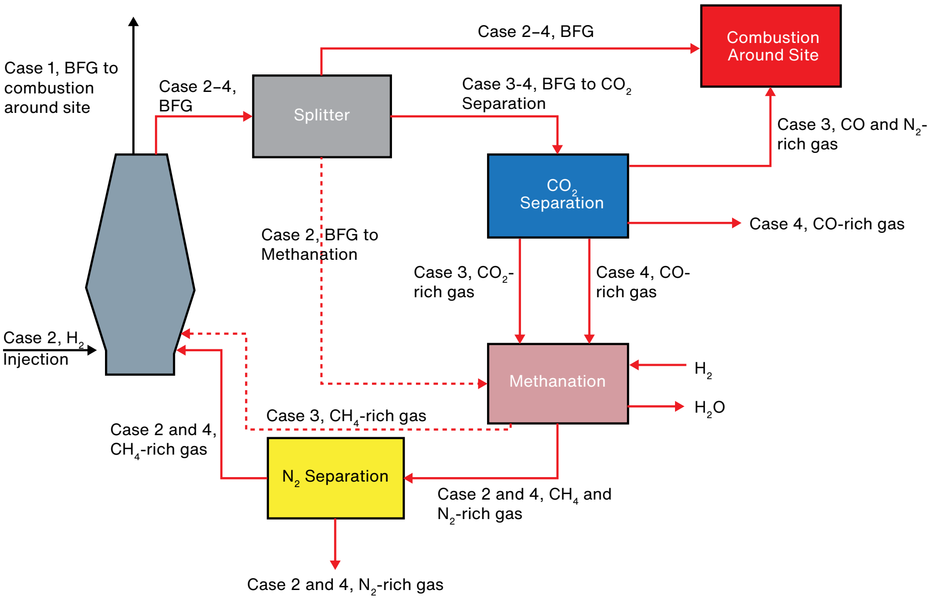
Parameter	Unit	Base case
Sinter/acid pellet/basic pellet ratio	%	0/25/75
Total oxide burden	kg/t HM	1,479
Coke rate	kg/t HM	418
Natural gas rate	kg/t HM	90
Slag rate	kg/t HM	212
Blast temperature	°C	1,100
O_2 in blast	vol%	28.0
Flame temperature	°C	1,900
Top gas temperature	°C	125
ETA CO	%	49.5
Hot metal (HM) yield	t LS/t HM	0.97
Liquid steel (LS) yield	t CS/t LS	0.98
Scrap ratio in BOF	%	8
BF direct emissions	kgCO_2/t HM	1,397
Total associated sitewide emissions	kgCO_2/t CS	1,770

transformational change will be needed to reduce emission further for integrated steel mills, such as SNG injection.

This article explores a medium-term transformational change with methanation that does not require significant changes to the existing BF assets at a steel mill, and instead requires addition of auxiliary equipment that allows for further emission intensity reduction of the steel being produced.

Figure 5

Flowsheets of major units and gas flows for all four cases investigated.



Impact of Synthetic Methane and Hydrogen as Alternative Injected Fuels

To evaluate the impact of BFG methanation and direct hydrogen injection on the BF operation and emissions, four cases were evaluated and compared to the base case defined earlier. In all methanation cases, a portion of the BFG was methanated and reinjected after various stages of processing. A scenario which only incorporates direct hydrogen injection, instead of using hydrogen for methanation, was also evaluated to understand if methanation can be used to overcome the limitations of hydrogen injection. For all cases, hydrogen was assumed to be available for purchase. The cases investigated are:

- Case 1: Direct hydrogen injection.
- Case 2: BFG methanation, nitrogen separation and reinjection.
- Case 3: BFG carbon dioxide separation, methanation of carbon dioxide–rich stream and reinjection.
- Case 4: BFG carbon dioxide separation, methanation of carbon monoxide rich stream, nitrogen separation and reinjection.

The major units and gas flows for all four cases are outlined in the overall flowsheet in Fig. 5.

Each case was evaluated on coke rate, hydrogen demand, direct carbon dioxide emissions from the BF, and overall emissions from the integrated steel mill and was compared to the base case. To determine the optimal operating conditions for each modeled configuration, the BF model was optimized within certain constraints. The constraints were formulated to minimize changes to base case operating conditions to represent scenarios where minimal changes to existing assets are required to affect an emission reduction. These constraints include:

- Top gas temperature ≥110°C.
- RAFT ≥1,900°C.
- Blast oxygen content ≤28%.
- Gas utilization = 49.5%.

Within these constraints, the amount of methanated recycled BFG was maximized to understand the potential impact on the emission intensity of the steel produced. The results of the four cases are summarized in Table 3.

The results show the main parameters for the various configurations: the hydrogen demand; the changes to the direct emissions from the BF; and the changes to sitewide emissions. The plantwide energy balance was considered as portions of the BFG will be consumed in methanation and not available for heating purposes elsewhere in the facility. This difference was reported as a change in electricity produced at the power generation site, assuming a 30% energy conversion efficiency.

For Case 1, pure hydrogen was injected directly into the BF, instead of being used for methanation as shown in Fig. 6.

The resulting BFG was exported for heating purposes around the plant. As seen in Table 3, pure hydrogen injection results in a decrease in the emission intensity; a slight increase in coke rate and an oxygen enrichment decreases to accommodate the change to the furnace heat balance. The direct hydrogen injection causes a 9.8% reduction in carbon dioxide emissions from the BF, which corresponds to a 6.5% emission reduction for the entire

Table 3

Modeled Alternative Gas Injection Scenario Results Summary

Parameter	Units	Base case: Natural gas injection	Case 1: Hydrogen injection	Case 2: BFG methanation + N_2 separation	Case 3: CO_2 separation + methanation of CO_2 stream	Case 4: CO_2 separation + methanation of CO/H_2 stream + N_2 separation
Blast/Raceway						
Hot blast (incl/O_2 enrichment)	Nm^3/ t HM	991	1,007	993	995	992
Specific O_2	vol. %	28.0	24.0	28.0	28.0	28.0
Blast temperature	°C	1,100	1,100	1,100	1,100	1,100
RAFT	°C	1,908	1,900	1,900	1,900	1900
Fuel						
Coke	kg/t HM	418	421	428	420	422
Natural gas	kg/t HM	90	—	—	—	—
Recycled gas (reducing gas)	kg/t HM	—	—	100 (81 $CH_4 + H_2$)	100 (86 $CH_4 + H_2$)	101 (84 CH_4 + 17 H_2)
H_2 demand	kg/t HM	—	29	36	39	31
Total fuel	kg/t HM	508	480	509	506	507
Synthetic natural gas						
Recycled top gas	vol. %	—	—	17.2	37.0	32.4
Carbon recycled	wt. %	—	—	16.4	17.1	16.5
SNG - CH_4	vol. %	—	—	85.4	95.7	86.0
SNG - H_2	vol. %	—	—	5.4	0.7	4.8
SNG – CO	vol. %	—	—	0	0	.0
SNG - CO_2	vol. %	—	—	4.4	0.9	0.6
SNG - N_2	vol. %	—	—	4.7	2.6	8.5
SNG - H_2O	vol. %	—	—	0.1	0.1	0.1
Top gas						
EtaCO	—	49.5	49.5	49.5	49.5	49.5
Temperature	°C	120	110	120	116	123
Direct (BF) CO_2 emissions (with CCS)	$kgCO_2$/ t HM	1,397	1,259	1,175	1,161	1,156 (947)

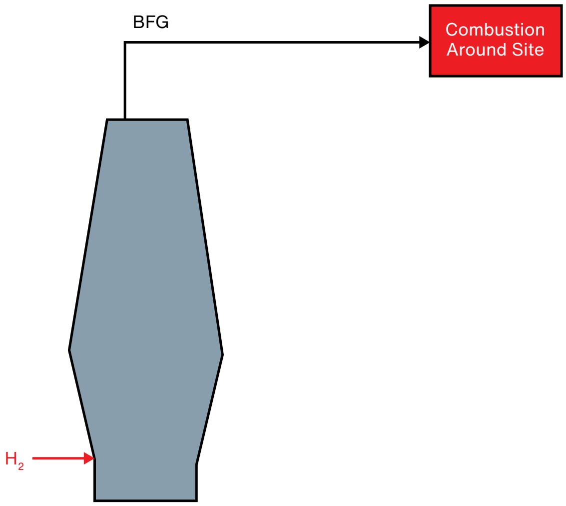
Table 3 (cont'd)

Parameter	Units	Base case: Natural gas injection	Case 1: Hydrogen injection	Case 2: BFG methanation + N_2 separation	Case 3: CO_2 separation + methanation of CO_2 stream	Case 4: CO_2 separation + methanation of CO/H_2 stream + N_2 separation
Entire steel mill implications						
CO_2 emissions intensity (with CCS)	$kgCO_2$/t CS	1,770	1,655	1,566	1,549	1,546 (1,349)
Δ CO_2 emission intensity (with CCS)	$kgCO_2$/t CS	–	–115	–204	–221	–224 (–421)
Change to plant energy balance*	kWh/t CS	–	+16	–73	+0	–145

*Change to plant energy balance is assumed to be the effect on purchased power, purchasing more if in deficit or purchasing less if in surplus.

Figure 6

Schematic for Case 1: Pure hydrogen injection.



steel mill value chain. Hydrogen use was limited by a combination of the heat capacity impact on RAFT and the top gas temperature due to the endothermic nature of hydrogen-based reduction. Blast oxygen enrichment was reduced to carry more nitrogen and its related sensible heat to the BF top; this led to a RAFT reduction which limited hydrogen injection. An additional benefit of hydrogen injection is that it increases the heating value of the BFG, increasing the energy available for use in other areas of the steel plant or for export.

The simplest methanation option was evaluated in Case 2, where portion of the BFG was methanated with hydrogen, as shown in Fig. 7.

The moisture generated from the methanation unit was condensed and the methanated offgas stream was sent to a nitrogen separation unit. Nitrogen removal is critical, as excess amounts of nitrogen limit the amount of SNG that can be reinjected back into the BF due to the large amount of energy needed to heat nitrogen up to raceway temperatures. In this case, a single-stage methanation unit was used, as only approximately 50% of the carbon exists as carbon dioxide, so a lower conversion rate was deemed to be acceptable. The results showed that a 15.9% reduction in the BF carbon dioxide emissions is possible, which corresponds to a 11.5% emission reduction for the entire steel mill value chain. Based on lower methanation conversion and nitrogen separation efficiency, the produced SNG had a higher level of impurities (nitrogen and carbon dioxide), which limited how much of the produced SNG could be reinjected into the furnace. The appeal of this case is that it has the simplest methanation configuration with only two additional process units needed, one methanation unit and one nitrogen separation unit. As a portion of the BFG is used in the methanation unit, the overall energy available for the remainder of the facility decreases slightly and may require the purchase of additional power for the integrated plant.

In Case 3, a portion of the BFG was sent to a carbon dioxide capture unit, and the high carbon dioxide concentrated tail stream was sent to a methanation unit, as shown in Fig. 8.

Case 3 is comparable to JFE's carbon recycling technology.[4,5] The configuration does not require nitrogen separation, as nitrogen is separated in the carbon dioxide capture unit and leaves with the carbon monoxide–rich syngas for site combustion, prior to methanation. In this case, a two-stage methanation unit is needed to achieve a sufficient conversion rate of the carbon dioxide feed to methane. As the conversion of carbon dioxide to methane requires an additional 33% amount of hydrogen on a molar basis when compared to the methanation of carbon monoxide, the hydrogen demand is the highest for this case. The results showed that a 16.9% reduction in the BF carbon dioxide emissions is possible, which corresponds to a 12.5% emission reduction for the entire steel mill value chain. The appeal of this case is that since the carbon dioxide in the BFG is the main source of carbon for SNG production, the separated carbon monoxide–rich tail can still be used as a heating fuel in the steel works, resulting in no net change to the overall plant gas/energy balance. The drawbacks of the case are that it requires three additional process units, a carbon dioxide separation unit and two methanation stages, and a higher hydrogen demand.

Figure 7

Schematic for Case 2: Methanation, nitrogen separation and reinjection.

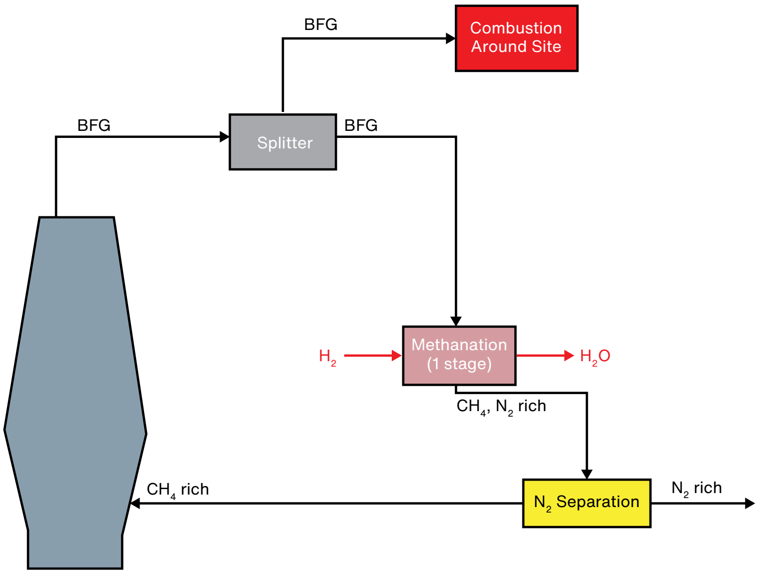
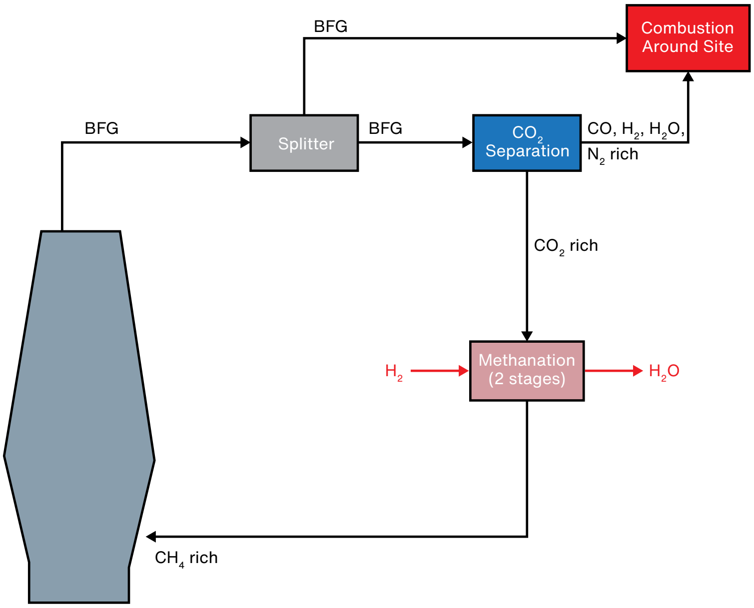


Figure 8

Schematic for Case 3: Carbon dioxide separation, methanation of carbon dioxide–rich stream and reinjection.



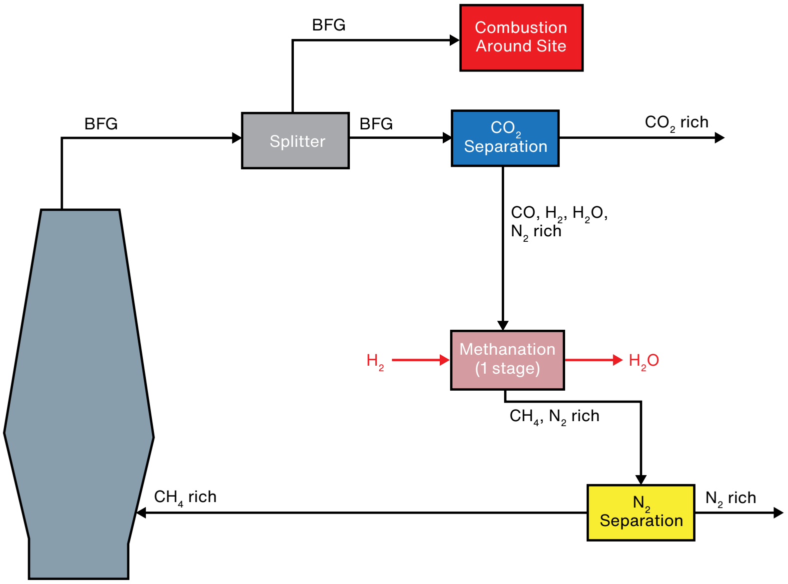
Case 4 was the last methanation configuration evaluated, where a portion of the BFG was sent to a carbon dioxide capture unit, and the separated syngas was sent to a methanation unit, as shown in Fig. 9.

The methanated stream contains nitrogen from the BFG so nitrogen separation is required after the methanation occurs. In this case, a single-stage methanation unit is needed to achieve a sufficient conversion rate of the carbon monoxide feed to methane. The results showed that a 17.3% reduction in the BF emission is possible, which corresponds to a 12.7% emission reduction for the entire steel mill value chain. The appeal of Case 4 is that the hydrogen requirement is the lowest, as the carbon source is mostly carbon monoxide instead of carbon dioxide. The Case 4 disadvantages are that it requires three additional process units — a carbon dioxide separation unit, a single methanation stage and a nitrogen separation unit — and has the largest reduction to the overall plant gas/energy balance. This large reduction in the plant gas/energy balance results from feeding carbon monoxide–rich gas from carbon dioxide separation to the methanation unit instead of being used for electricity generation on-site. Case 4 produces a concentrated carbon dioxide stream, which presents an opportunity for carbon capture, sequestration, or utilization (CCU/S). If the carbon dioxide is sequestered/utilized, a 32.2% reduction in the BF emission or a 23.8% emission reduction for the steel mill value chain would result.

All cases were modeled using similar calculation steps and assumptions. That said, it is challenging to compare the cases across all variables, so a hydrogen efficiency metric was developed. Hydrogen-specific consumption to abate carbon dioxide emissions was designated as the overall facility emission carbon dioxide reduction divided by the amount of hydrogen used to achieve this reduction. Using this criteria, Case 4, was the most efficient at 7.3 kg CO_2/kg H_2 deployed and could increase to 13.6 kg CO_2/kg H_2 deployed if CCU/S is considered. The efficient use of hydrogen for all cases is shown in Fig. 10.

Figure 9

Schematic for Case 4: Carbon dioxide separation, methanation of carbon monoxide/hydrogen-rich stream, nitrogen separation and reinjection.



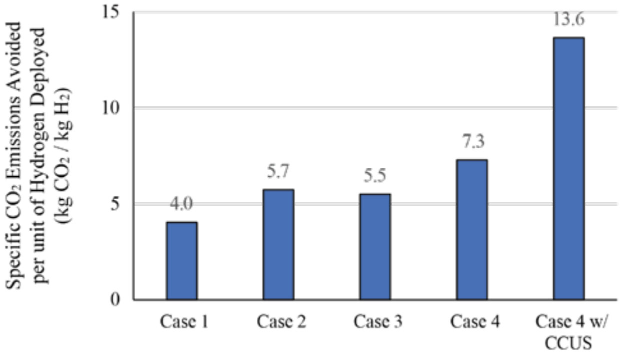
Conclusion

Methanation of blast furnace top gas was found to be a more efficient way of introducing hydrogen to BF operations to reduce carbon dioxide emissions when compared to a direct hydrogen injection. In all cases where BFG was methanated and the SNG recycled back to the BF, the emission reduction per unit of hydrogen was higher than directly injecting hydrogen to the BF. This was driven by the added benefit of recycling carbon from BFG to the BF and avoiding the related carbon dioxide emissions compared to direct hydrogen injection. In Cases 2 and 4, where the carbon monoxide and hydrogen portion of the BFG was recycled to the methanation unit, the purchased hydrogen demand for methanation was minimized due to the lower molar requirement for methanating carbon monoxide compared to carbon dioxide.

While the total emission reduction potential is higher with methanation, the question remains if the additional reduction potential justifies the higher CAPEX required for the gas separation and methanation units. Compared to the base case, the emission reduction with methanation and SNG injection ranges from 11.5 to 12.7% over the steel mill value chain (up to 23.8% if CCU/S is considered), whereas direct hydrogen injection would only achieve a 6.5% reduction. These results suggest that methanation warrants further investigation if a steel producer is pursuing alternative fuel gas injection as a carbon dioxide emission reduction strategy.

Figure 10

Specific carbon dioxide emissions avoided per unit of hydrogen deployed for all cases.



Combined with oxygen blast furnace technology, further reductions in carbon dioxide emissions may be possible, as illustrated by the configuration being developed by JFE.[4,5] The configurations evaluated in this article could be used as precursor technology steps to de-risk methanation applications in blast furnace operations as the challenges of switching to an OBF are de-risked in parallel. The results presented indicate that methanation has promise to reduce carbon dioxide emissions and is a better use of purchased hydrogen than direct injection. Methanation synergies with blast furnace applications warrant further study.

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