

Decision Support Tool for Sustainable Small to Medium-Volume Natural Gas Utilization

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ABSTRACT

This study presents a simple tool to provide decision-makers data that will facilitate informed decisions in selecting utilization for small- to medium-scale utilization of stranded natural gas resources that would otherwise be flared. The methodology involves the simulation of different natural gas utilization technologies on Aspen Plus simulation software and utilizing the results to develop a tool on python that enables the user to assess recoverable valuable products from different natural gas profiles. Ten utilization technologies were implemented and six different natural gas profiles (rich and lean) were used as case studies to ascertain the capabilities of the tool. The results provide the user with the Net Present Values (NPV) of different technologies and the most profitable or infeasible utilization technology. The results also show the potentials of utilizing the gas over flaring. For very small volumes of gas the results favored the compressed natural gas (CNG) with positive NPV, and next electricity production. Small to medium volumes of lean gas favoured the turquoise methanol. Mini- Liquefied Natural Gas (LNG) were the least profitable especially for small volumes. This tool can facilitate the evaluation of several gas profiles to assess the impact of utilizing natural gas over flaring in the sustainable future paradigm.

Keywords: Aspen Plus, Methanol, Energy Storage, Carbon Dioxide Capture, Alternative Fuels.

INTRODUCTION

The global efforts aimed at mitigating carbon emissions include curbing gas flaring. Several initiatives have been introduced by stakeholders, including the World Bank's zero routine gas flaring by 2030, launched in 2015, to achieve this goal of reducing CO₂ emissions due to gas flaring. The initiatives led to the development of a gas flaring tracking tool, the Global Gas Flaring Reduction (GGFR) initiatives that foster the development of technologies for the valorization of small natural gas volumes that are routinely flared for safety, logistical, and economic constraints [1]. However, flaring continues to contribute significantly to global emissions, and the last World Bank report observes a reversal of the significant progress made by the GGFR initiatives with an increase in gas flaring volume by 7% [2]. Therefore, innovative solutions are required to facilitate the efficient and sustainable valorization of these otherwise stranded gas volumes to reduce resource waste and curb emissions [3-4].

Literature review

Numerous studies from oil- and gas-producing countries have evaluated different routes to valorize stranded natural gas resources and avoid flaring. A study that reviewed the different natural gas utilization technologies that can be applied to mitigate flaring showed that gas-to-liquids producing Syncrude, methanol (MeOH) or dimethyl ether (DME), gas-to-wire, which generates electricity and heat in some cases, and natural gas liquid extraction or dry gas liquefaction are economically favorable for small- to medium-scale gas volumes [3]. A detailed World Bank report demonstrates the different technological innovations in the market with the potential to handle small gas volumes that would widely be flared [4]. In the same way, [5] did an environmental and economic analysis of various types of gas feed to group the utilization technologies. This study proposes the integration of data from existing research with new technologies to develop a tool that quickly checks if a gas profile is available for other uses besides flaring.

METHODOLOGY

Tool overview

The decision-making tool proposed in this study consists of two parts, described below: the first one, that calculates technology-specific prices, costs and yields, is implemented a priori in ASPEN Plus. The second one, that calculates Net Present Values and obtains the environmental analyses with user-supplied data, is an application programmed in Python. An overview of the tool is exhibited in Fig 1.

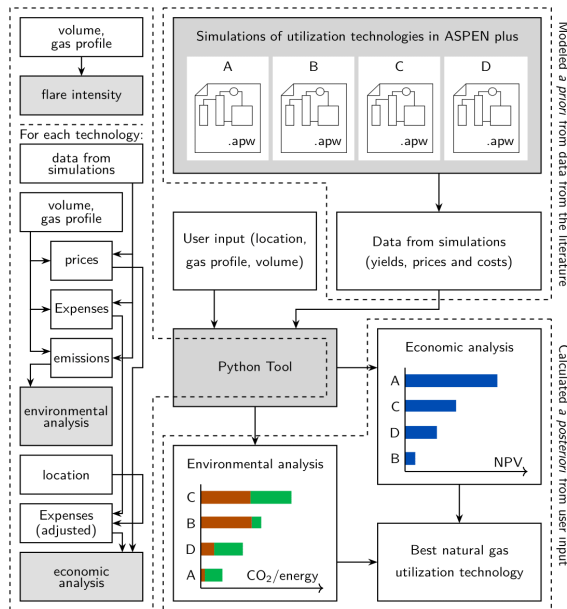


Figure 1. The decision-making tool methodology.

Initially, data from the literature was used to implement simulations of all utilization technologies and pretreatments. These simulations returned capital and operational expenses for a plant with fixed size and yields that could be attainable by each process (and, therefore, the prices of their output streams).

The data obtained through the simulations was then incorporated into the Python tool. This tool reads data supplied by the user (such as gas profile and volume, gas field location, and carbon tax) and calculates, firstly, the emissions if the gas is flared, then, it yields, net present values (NPV) for each utilization technology, considering scale, shipping and installation multipliers (for CAPEX adjustment) and the local discount rate. Besides the NPV, the CO₂-equivalent emissions and energy usage are also obtained. For each utilization technology, the cheapest feasible pretreatment was selected, and the economic (NPV) and environmental (CO₂ emissions and energy usage) analyses are sorted and presented to the user, who should select the best technology.

Assumptions

The following assumptions were made in the collection of data and the tool design: Onshore application of technologies, small to medium scale from 0.1 – 20 MMSCFD, Steady state process simulations, HHV values at 15°C and 1 atm, modular units, project implementation of 6-12 months, average gas profile for 10 years, all products are utilized within the vicinity hence transportation costs are not included.

Data collection

The natural gas field selection was based on the world bank platform for gas flaring monitoring [1]. Gas fields from 5 continents with gas flaring records were selected based on available field data representation as presented in Table 1.

Table 1: Utilization technologies simulation data.

Process	Conditions	Ref
Full Fractionation	Dry gas (%):C1-98.9, C2-35, C3-5	[4,7]
NGLs removal	Dry gas (%):C1-98.9, C2-65, C3-5	[4]
Dehydration	Dry gas C3+<5%	[7]
LNG	-154°C	[7]
CNG	250bar	[4]
G MeOH	S:C=4, 20bar, 850-900°C	[8]
T MeOH	1 bar, 1200°C	[8,9]
NGCCT	7bar, GT: 950°C, ST:480°C, 42 barg	
NGCCT+CCS	CCS _{in} : 42 bar, CO _{2in} - 0,093, CO _{2Out} : 150 bar,98.5%	[10]
NGT(CHP)+CCS	7bar, GT: 950°C, Steam:184°C, 10 barg	[11]
NGT(CHP)	Steam:184°C, 10 barg	[12]
NGT	7bar, GT: 950°C	[12,13]
NGE		[4]

Several reviews on the different valuable products from small scale gas utilization technologies to prevent gas flaring were analysed. This study classified the most common profitable valorization technologies into dry gas liquefaction and compression (mini-LNG, CNG) for storage and transport, gas to liquid/chemicals (methanol was selected) and gas to wire (electricity production) technologies. Ten (10) prospective utilization technologies to obtain valuable products were considered based on available data [2]. These technologies were simulated in Aspen Plus to obtain thermodynamics, mass and energy balance data used for technology assessment. The references used for the different technologies are presented in Table 1.

Process Simulation

The processes considered were simulated in Aspen plus on a basis of an initial feed gas flowrate of 1 MMSCFD for simplicity. The super structure in Fig 2 represents the different scenarios for simulations carried out using data from the literature as in Table 1.

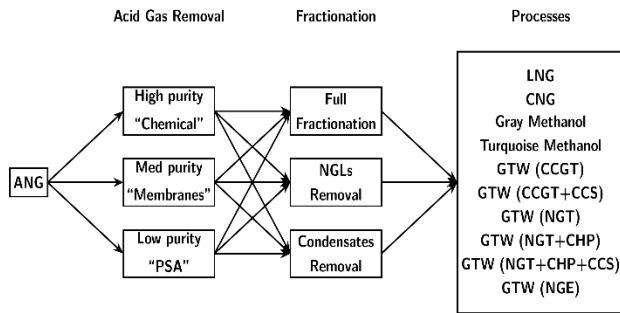


Figure 2. Process case study superstructure.

The Aspen simulation includes the cleaning requirements for different technologies. The acid gas removal and NGLs removal were represented with the SEP component model and the separation parameters obtained from the detailed reporting in the literature [2]. Three acid gas removal purity levels were considered, based on the different purity levels required for different technologies. Similarly, depending on the gas quality, the removal of NGLs may be required for some utilization processes. Thus, different scenarios are simulated for full fractionation into individual products, de-methanization to remove NGLs or basic dehydration (for a clean lean gas) is required for each utilization technology or different valuable products produced.

Dry gas Storage (Mini-LNG and CNG)

Traditionally, large scale volumes of natural gas are cooled to liquid state at very low temperatures (-145°C to -165°C) for ease and safe transport over long distances where it would be too expensive or infeasible to install. The introduction of the mini-LNG plants facilitates the processing of gas into LNG, the simulation of the LNG plant was carried out based on [2], [3]. CNG can serve as a virtual pipeline, it involves natural gas compression by 250 times (250bar) at ambient temperature. It is used to transport or store gas over short distances for a short period.

Gas to Wire (Microturbines, Small-scale Engines)

The production of electricity is the most common utilization of natural gas as it accommodates a variety of gas profiles. The use of micro turbines and small gas engines for the combined heat and power process is commonplace in oil and gas production sites. However, this process involves the combustion of the fuel gas which produces CO₂. In this study, the application of carbon capture and storage (CCS) was explored. The CO₂ mole fraction in the exhaust stream is very low. Hence, for the

application of CCS the exhaust gas is recycled to improve the CO₂ mole content and less air is required for the combustion as implemented in this work for the NGCCGT with CCS case [4]. Whereas without the application of CO₂, the excess gas required is more to maintain the turbine inlet temperature as applied here [5], [6].

Gas to Liquid/Chemicals (Methanol Synthesis)

The gas to liquid or chemical where natural gas is converted to syngas through steam reforming and subsequently higher hydrocarbons like diesel or the syngas converted to MeOH (Grey methanol), DME or anhydrous ammonia. For small volumes, methanol is usually more profitable and avoids the production of CO₂. Equations 2-4 shows the chemical reactions for steam reforming methanol synthesis.

Currently, small-scale CO₂ hydrogenation to produces methanol emerges to facilitate renewable (green) methanol. However, green methanol is not cost competitive with conventional methanol. Turquoise methanol (T MeOH) shows the potential to be more competitive. The process involves CO₂ hydrogenation using pure hydrogen from methane pyrolysis. Based on Equation 1 methane is split into H₂ and solid C. This study applied the technology using a regenerative heat exchanger reactor (RHER) to facilitate heat exchange between reactant, bed and products in a counter-current flow, reducing energy consumption and heat waste as shown in Figure 2.

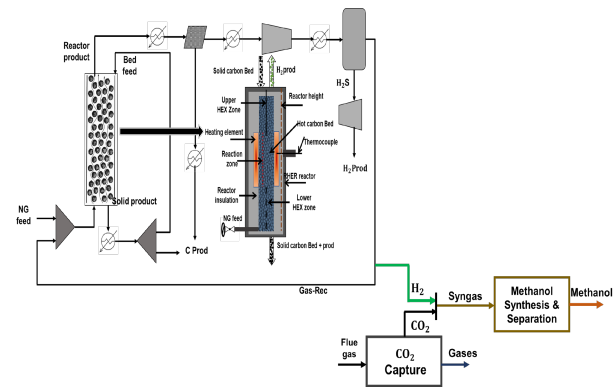
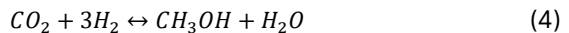


Figure 3. Turquoise Methanol Synthesis.

The RHER uses electricity through ohmic heating. Therefore, when renewable electricity is used the technology does produce CO₂ but valuable carbon as a by-product adding to the economic competitiveness of the product. Thus, it is included as an emerging technology in this study based on [7].

Performance Indices

To evaluate the different technologies, some sustainability (material, energy, economic and environmental) metrics were calculated.

The emission of gas if flared or recoverable products and byproducts if gas is used are calculated based on emission intensity or product yield:

$$CO_{2prod} = \frac{(\%VW_{CO_2})_t}{100\%} + \sum_{y=1}^Y \left\{ \varepsilon * \frac{(\%C_y)_t}{100\%} * CNM_y \right\} \quad (5)$$

$$E_{CO_2} = \left[(V_{flare})_t * \frac{MW_{CO_2}}{MVC} * K * CO_{2prod} \right] \quad (6)$$

where CO_{2prod} accounts for the CO_2 produced from combustion of hydrocarbons in the feed gas and the CO_2 components before combustion, ε is the flare efficiency, y is the index for carbon containing components other than CO_2 , $\%VW$ is the mole concentration of CO_2 in the gas stream, t is the time period under consideration CNM is the precursor mole number of carbon. E_{CO_2} is the CO_2 emission intensity, V_{flare} is the volume of gas to be flared, MW is the molecular weight, MVC is the molar volume conversion factor and K is the unit conversion factor.

Alternatively, all emissions can be calculated using the heating value and emission factor for each pollutant. This is given by

$$E_i = K * \varepsilon * \sum_{t=1}^T \left((V_{flare})_t * HHV * EF_i \right) \quad (7)$$

where E_i is the emission intensity of pollutant, HHV is the higher heating value, EF_i is the emission factor for each pollutant.

The product yield is calculated based on the type of product such as gas, chemical or electricity as follows:

$$Product\ yield(\alpha) = \frac{F_{output}}{F_{input}} = \frac{F_{output} * HHV}{F_{input} * HHV} \quad (8)$$

$$Q_{Prod,mat}(kg/h) = Q_{gas} * \alpha(j) \quad (9)$$

$$Q_{Prod,elect}(kW) = Q_{gas} * \alpha(j) * HHV \quad (10)$$

where Q is the flowrate, $\alpha(j)$ is the product yield for process j . The HHV of all NG components was obtained from Aspen Plus and for each gas composition, the summation of the product of each component fraction and its HHV was used.

For this study, the rate of energy consumption, the efficiency, the CO_2 equivalent emission or avoided by each technology was also computed:

$$E_{rate} = \frac{E_{input}}{Q_{product}} \quad (11)$$

$$\varepsilon_j = \frac{E_{output}}{E_{input}} * 100\% \quad (12)$$

$$CO_{2rate} = \frac{FCO_{2,product} + FCO_{2,utilities}}{Q_{product}} \quad (13)$$

Likewise, the economics metrics including the capital cost (CAPEX), operating cost (OPEX), rate of returns

on investment (ROI), payback period and the production cost were computed:

$$ATCI = CAPEX * \frac{i(1+i)^t}{(1+i)^t - 1} \quad (14)$$

where $ATCI$ is the annualized total capital investment (CAPEX), the annuity factor using the interest i and the time period t . The fixed operating cost FOC including the labor cost, general maintenance etc., VOC is the variable operating cost consisting of the energy cost, feed cost, catalyst cost etc. Although in this case, the feed cost is zero being a waste gas.

$$OPEX = FOC + VOC \quad (14)$$

$$Product\ cost = \frac{CAPEX * OPEX}{Q_{product}} = \frac{TAC}{Q_{product}} \quad (15)$$

The total annual cost (TAC) is used to calculate the production cost and the profit, and the profit is used to compute the rate of returns (ROR), and the payback period.

$$Profit = Q_{product} * P_{price} - TAC \quad (16)$$

Case Studies

To evaluate the capabilities of the model for quick decisions, a few case studies were analyzed, encompassing different sizes (from 0.5 MMSCFD to 20 MMSCFD), geographical locations and gas profiles. The data were selected from the world bank gas flaring tracker [1], six fields were selected. Three of them with a rich gas profile, from Saudi Arabia (SAU), the United States (USA) and the United Kingdom (UK), shown in Table 2, and three of them with a lean gas profile, from Brazil, Australia and Nigeria, shown in Table 3

Besides this analysis, another case study was performed, introducing an increasingly large carbon tax and checking its impact over the models' choices.

RESULTS

Inline with the user interface presented in Fig S2, the first tab enables the decision maker to initiate the evaluation by providing the profile of the natural gas, the alternatives are provided in the second tab and the user is able to select the preferred result.

The results are presented in the third tab, these results from the evaluation of the model assessing different gas profiles from different locations considered are discussed:

Rich Gases

Three of the case studies concerned rich gases, that is, gases with a higher concentration of heavier hydrocarbons as shown in Table S1 of the supplementary material.

Despite the physical feasibility of all utilization

technologies with the Saudi gas field, the production of LNG and the usage of Natural Gas Engines are not profitable, with a negative Net Present Value (NPV) of 7.028 million dollars for the former and 4.862 million dollars for the latter. All other utilization technologies can be made profitable through an optimal choice of pretreatment and cleaning processes. The best performing utilization technology was the production of CNG, after chemical Acid Gas removal and simple Natural Gas Liquids removal. This technology yields a positive NPV of 10.377 million dollars.

On the other hand, the gas from the American field can always be profitably explored, regardless of choice of utilization technology, with even the least lucrative choice, LNG production, yielding a modest, but positive, NPV of 7.65 million dollars, after a membrane-based acid gas removal step and after separation of natural gas liquids. Meanwhile, the best choice, turquoise methanol production, exhibits a positive NPV of 72.636 million dollars, using the cheapest acid gas removal technology (PSA) followed by NGL separation.

Finally, the British field shows results very similar to the American ones, when the proportions are taken into account: the least profitable utilization technology is the same (LNG with membrane cleaning and NGL separation), and the most profitable is very similar (also Turquoise Methanol production after NGL separation, but the higher acid gas fraction must be removed through a chemical process, more efficient but also more expensive). The NPVs range from 56.477 million dollars (LNG) to 325.49 million dollars (for the Turquoise Methanol).

Lean Gases

The other three gas fields analyzed in this work are lean gas fields, that is, with a higher methane content. as shown in Table S1 of the supplementary material.

The Brazilian field can profitably deploy all utilization technologies, with the exception of LNG production. In this situation its NPV is negative and has a value of 2.759 million dollars. On the other hand, the production of CNG is the most profitable choice, with a Net Present Value of 8.292 million dollars. This difference originates from the impurity tolerances of LNG and CNG: while the first must be of higher purity, demanding expensive and complex treatment systems, the second is laxer. Hence, cheaper and simpler technologies can be applied to its purification before usage. Indeed, while the best case for LNG demanded full fractionation and chemical acid gas removal, the most profitable cleaning process for the CNG needed no acid gas removal.

The Australian field also shows the trend of Methanol synthesis being the most profitable choice above a certain gas volume. Despite all choices yielding positive NPVs, the list was headed by Turquoise and Gray Methanol synthesis, with a simple acid gas removal and natural

gas liquids separation.

These utilization technologies achieved an NPV of 59.903 million dollars and 57.903 million dollars, respectively. The bottom of the list, as before, is still occupied by the LNG production, with an NPV of 6.584 million dollars.

Lastly, the gas from the Nigerian field is best explored through the synthesis of Methanol: Turquoise and Gray Methanol once again headed the list, with NPVs of 417.56 million dollars and 347.71 million dollars, respectively. The worst, but still profitable, utilization technology for this field is not, however, LNG production as previous examples show, but electricity generation using Natural Gas Engines (NGEs).

Carbon Tax Impact

To assess the economical impacts of a Carbon Capture & Storage technology, 500 new simulations of the United Kingdom gas field described in the previous section were analyzed. Unlike the previous simulations, a Carbon Tax is introduced, spanning from zero to 20 USD/tCO₂ emitted. The Net Present Values for different technologies in these circumstances are shown in Figure 3.

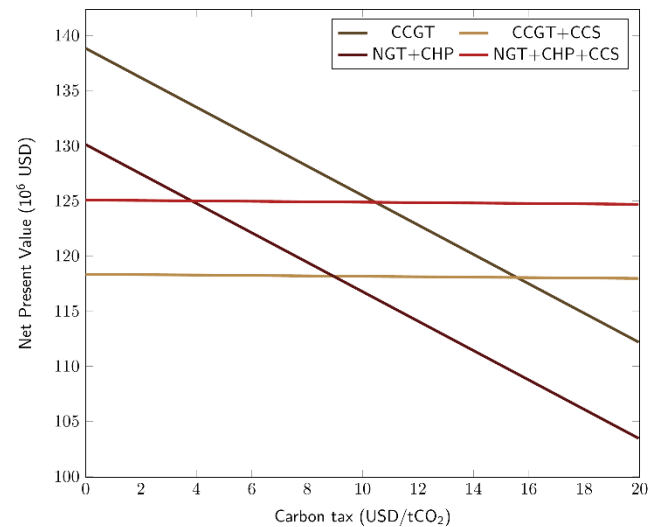


Figure 4. Net Present Values of Gas-To-Wire utilization technologies, with a growing Carbon Tax

It can be observed that, for these Gas-To-Wire technologies, a Carbon Capture system becomes economically superior for a Carbon Tax greater than 10 USD/tCO₂.

CONCLUSION AND FURTHER WORKS

This work presents a tool to provide decision-makers data that will facilitate informed decisions in selecting utilization for small- to medium-scale utilization of stranded natural gas resources that would otherwise be

flared. This would mitigate flaring and reduce waste of valuable resources. The tool also provides data for achieving improved economical performance and sustainability by selecting profitable technology for each gas profile and volume, accounting for the requirements of each one. The application of this tool to a collection of case studies enables quick assessments that impact sustainable future policies, since several scenarios can be assessed before detailed project development. Case study results favored CNG followed by electricity as expected given that they have the least cost. However, CNG can only be applied to short distances within the locality of production. The study also showed the potential for producing clean chemicals, such as emission-free turquise methanol.

Despite considering location for installation and shipping costs, the uncertain and varying factors (such as product prices and transportation costs) were assumed constant, hence limiting the study. Further works will include the implementation of a stochastic model and the possibility to account for future market movements to greatly improve the tool.

DIGITAL SUPPLEMENTARY MATERIAL

All source code written for this project is publicly available at GitHub in the following link <https://github.com/pedro-callil/flare-alternatives> as well as LAPSE:2025.0038

ACKNOWLEDGEMENTS

This research was financially supported by the Coordination of Superior Level Staff Improvement (CAPES) grant no. 88887.464619/2019-00, PROEX program and RCG21/FAPESP (2020/15230-5). Galo A. C. Le Roux acknowledges the fellowship from National Council for Scientific and Technological Development CNPq (311550/2022-3). Pedro H. Callil-Soares acknowledges the grant 2023/04683-7, São Paulo Research Foundation (FAPESP), Patience acknowledges Petroleum Technology development fund – Nigeria (PTDF).

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