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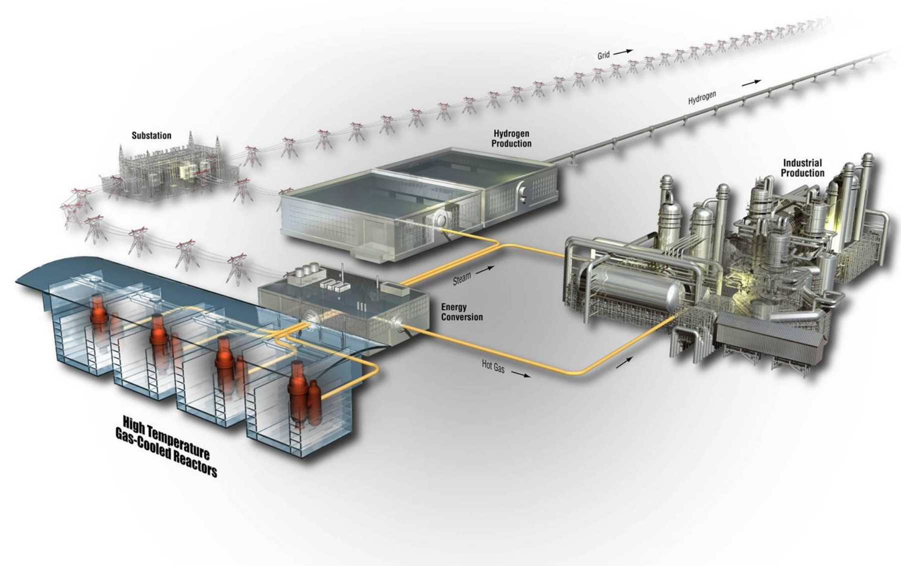
Assessment of the SRI Gasification Process for Syngas Generation with HTGR Integration – White Paper

Anastasia M. Gandrik

April 2012



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ABSTRACT

This white paper is intended to compare the technical and economic feasibility of syngas generation using the SRI gasification process coupled to several high-temperature gas-cooled reactors (HTGRs) with more traditional HTGR-integrated syngas generation techniques, including:

- Gasification with high-temperature steam electrolysis (HTSE)
- Steam methane reforming (SMR)
- Gasification with SMR with and without CO_2 sequestration

CONTENTS

FIGURES

TABLES

ACRONYMS

HHV	Higher heating value
HTGR	High-temperature gas-cooled reactor
HTSE	High-temperature steam electrolysis
MTG	Methanol to gasoline
PRB	Powder River Basin
IPCC	International Pittsburgh Coal Conference
IRR	Internal rate of return
SMR	Steam methane reforming
TCI	Total capital investment

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INTRODUCTION

This white paper is intended to compare the technical and economic feasibility of syngas generation using the SRI gasification process coupled to several high-temperature gas-cooled reactors (HTGRs) with more traditional HTGR-integrated syngas generation techniques, including:

- Gasification with high-temperature steam electrolysis (HTSE)
- Steam methane reforming (SMR)
- Gasification with SMR with and without CO_2 sequestration

SRI PROCESS OVERVIEW AND MODELING APPROACH

The SRI process combines coal gasification and SMR in a single high pressure reactor, which is operated at 1,015 psi. In traditional gasification, coal is combusted with oxygen to provide heat for coal devolatilization and char gasification. SRI has developed a novel concept where this heat is provided by electric heaters coupled with reforming for hydrogen production, thereby reducing/eliminating the CO_2 produced in the gasifier. Literature information does not provide specific detail on the conversion of electricity to heat for the gasifier, for this study a baseline efficiency of 85% was assumed.

The SRI gasifier was modeled similarly to the Shell gasifier described in TEV-672. However, rather than supplying oxygen to meet a specific reactor outlet temperature, the amount of electric heat input to the system was varied to achieve a syngas outlet temperature of 2,732°F. Steam was fed at 15% excess[1]. 7% of the natural gas and 2% of the coal feed remains unconverted. Finally, the natural gas feed was varied to achieve the syngas H_2, CO, CO_2 ratio for methanol production:

$$\frac{H_2 - CO_2}{CO + CO_2} = 2.10$$

Heat is recovered from the syngas to preheat the natural gas and steam feeds to 1,112°F. The syngas remains well above the temperature where whisker carbon is formed from the Boudouard reaction; however, given the high temperature and pressure this heat exchanger would likely be made of specialty materials. Sulfur is removed from the syngas using the Rectisol process; however, the Selexol process could also be used. Sulfur removal differs from that described in TEV-672 as a pure CO_2 stream is not produced due to the fact that all CO_2 produced in the gasifier is required for methanol production.

For verification of the process information presented by SRI at the International Pittsburgh Coal Conference (IPCC) the SRI gasifier was inserted into the methanol to gasoline (MTG) coal model developed by the INL as documented in TEV-667, in order to accurately capture the recycle gas composition and flowrate which is fed to the SRI gasifier. This recycle flow will have a large impact on how much natural gas is required by the process. It was assumed that the amount of light gas generated for methanol to jet fuel should be fairly similar to the amount generated in the MTG process. Both processes use methanol as an intermediate; hence the H_2/CO ratios required are consistent.

[1] 15 mol-% excess assuming that all steam reacts with the carbon fed to the reactor.

It was determined, based on the higher heating value (HHV), that the SRI presentation assumed the same Powder River Basin (PRB) coal type with 28.09% moisture that INL has used in previous Aspen Plus models. Also, based on the HHV presented the natural gas feed is assumed by SRI to be pure methane. The presentation was not specific on how much the PRB coal was dried prior to gasification; hence several dryness levels were assessed. The model looked at no drying, drying to 12% (the most likely scenario for a PRB coal), drying to 6%, and drying to 0% moisture. Based on information from Shell, drying a high moisture content coal like PRB to less than 12% may not be technically feasible as a portion of the moisture is actually locked into the coal and hence is not released until devolatilization.

The moisture content of the coal after drying and gas preheat levels had no impact on the required natural gas feed, only the amount of electrical heat required for the gasifier. The model predicted a natural gas feed rate of within 2% of the value listed in the presentation, which is extremely close given the limited information available to model the process. However, the model was farther off when comparing the electrical heat requirement.

Assuming less than 1% heat loss in the gasifier and 85% efficiency for heat from electricity requires an electrical input of 4,379 MWe, which is 34% higher than the 3,274 MW listed in the presentation, for coal dried to 12% moisture and preheated to 220°F, which is considered the most reasonable scenario. Looking at various coal preheat and coal drying levels only decreases the electrical input to 4,284 MWe, for the assumed heat loss and heat generation efficiency. If no losses are assumed and 100% conversion efficiency from electricity to heat is assumed, the required electrical input decreases to 3,641 MWe for 12% moisture and 220°F coal preheat, which is still greater than the value listed in the presentation. Even assuming the coal can be dried to 0% moisture, the amount of electricity is almost 9% higher than the value listed in the presentation. For full results, see Table 1.

Table 1. SRI case comparison.

	Baseline	1	2	3[2]	4	5	6	7
Coal Feed Rate (ton/day)	1,352,000	1,352,000	1,352,000	1,352,000	1,352,000	1,352,000	1,352,000	1,352,000
Moisture Content After Drying (%)		28.09	28.09	12	12	6	6	0
Dry Coal Feed Rate (ton/day)		1,352,000	1,352,000	1,104,799	1,104,799	1,034,280	1,034,280	972,223
Coal Preheat Temperature (°F)			450	220	450	220	450	450
Methane Feed Rate (lb/hr)	690,739	701,491	701,491	701,491	701,491	701,491	701,491	701,491
%-Error from Baseline		1.6	1.6	1.6	1.6	1.6	1.6	1.6
Gasifier Heat Input (MWt)		3,823	3,774	3,722	3,687	3,694	3,662	3,647
Electricity Required – 85% Eff. (MWe)	3,274	4,498	4,439	4,379	4,337	4,345	4,308	4,284
%-Error from Baseline		37.4	35.6	33.8	32.5	32.7	31.6	30.8
Electricity Required – 100% Eff. w/ no Losses (MWe)		3,741	3,692	3,641	3,605	3,612	4,212	3,560
%-Error from Baseline		14.3	12.8	11.2	10.1	10.3	9.4	8.7

SYNGAS GENERATION TECHNICAL COMPARISON

For all processes only syngas production and cleaning are modeled, this allows for a simple comparison of syngas generation without complicating the models with light gas recycles, which will be present to a varying degree for all syngas production techniques. All models include a syngas compressor which pressurizes the syngas to 1,090 psi in preparation for methanol production.

All processes were modeled to produce approximately 450,000 MMBTU/hr of syngas for methanol production. The following figure and table summarize the material and energy balances for the syngas generation techniques analyzed. The results presented in the table assume CO_2 sequestration where applicable.

All processes are technically feasible for syngas generation. However, integration of HTSE with gasification and the SRI gasifier requires an extremely large amount of electrical input to the system, which has a large impact on the process economics.

[2] Most likely scenario.

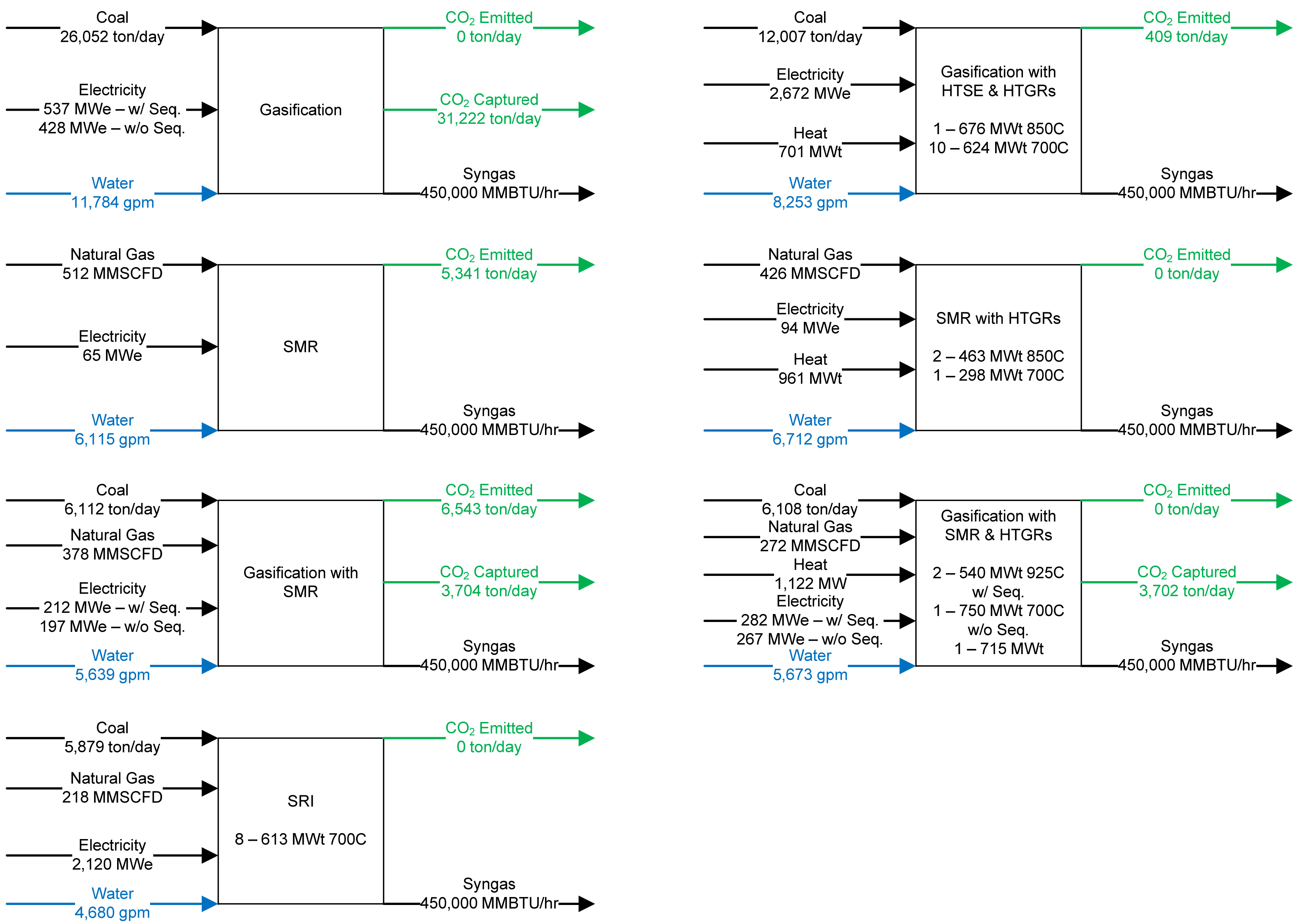

Figure 1. Syngas generation comparison modeling case material balance summary.

Table 2. Syngas generation comparison modeling case study results.

	Gasification	**Gasification w/ HTSE & HTGRs**	**SMR**	**SMR w/ HTGRs**	**Gasification w/ SMR**	**Gasification w/ SMR and HTGRs**	**SRI w/ HTGRs**
Inputs							
Coal Feed rate (ton/day)	26,052	12,007	N/A	N/A	6,112	6,108	5,879
Natural Gas Feed Rate (MMSCFD)[3]	N/A	N/A	512	426	378	272	218
% Carbon to Liquid Product	45.0	97.7	83.0	100.0	70.9	86.1	98.9
HTGR Thermal Input (MW_t)	N/A	6,916	N/A	1,224	N/A	1,830	4,904
Outputs							
Syngas Produced (MMBTU/hr)	450,000	450,000	450,000	450,000	450,000	450,000	450,000
Utility Summary							
Power Consumed (MWe)	-537	-2,672	-65	-94	-212	-282	-2,120
Water Consumed (gpm)[4]	11,784	8,253	6,115	6,712	5,639	5,673	4,680
CO_2 Summary							
Total CO_2 Produced (ton/day)	*31,222*	*409*	*5,341*	*0*	*10,247*		*0*
Emitted	0	409	5,341	0	6,543	0	0
Capturable	31,222	0	0	0	3,704	3,702	0
Nuclear Integration Summary							
Electricity to Process (MWe)	N/A	2,672	N/A	94	N/A	282	2,120
HTGR Heat to Process (MWt)	N/A	701	N/A	961	N/A	1,122	N/A

[3] Standard temperature of 60°F.

[4] Does not include water usage for HTGR

SYNGAS GENERATION ECONOMIC COMPARISON

The economic viability of the syngas generation processes was assessed using standard economic evaluation methods, specifically the internal rate of return (IRR). The economics were evaluated for the conventional and nuclear-integrated cases described in the previous sections. The total capital investment (TCI), based on the total equipment costs; annual revenues; and annual manufacturing costs were first calculated for the cases. The present worth was then calculated based on the annual after tax cash flows. The price of syngas to achieve a 12% IRR was determined for each case as a function of the natural gas purchase price and taxes on carbon emissions. Table 3 lists the economic assumptions used for the analyses. It was assumed that the SRI gasifier would have a capital cost comparable to the Shell gasifier.

Table 3. Economic assumptions.

	Assumption
Construction Information	
Preconstruction Period	6 months
Nuclear Construction Period – per Reactor	36 months
Reactor Startup Staggering	6 months
Fossil Construction Period – per Train	36 months
Train Startup Staggering	6 months
Percent Capital Invested Each Year	S-Curve Distribution
Plant Startup Information	
Startup Time	12 months
Operating Costs Multiplier	1.2
Revenue Multiplier	0.65
Economic Analysis Period	30 years
Availability	90%
Inflation Rate	3%
Debt to Equity Ratio	50%/50%
Loan Information	
Interest Rate on Debt	8%
Interest on Debt During Construction	8%
Loan Repayment Term	15 years
Tax Information	
Effective Tax Rate	35.9%
State Tax Rate	6%
Federal Tax Rate	35%
MACRS Depreciation Term	15 year life
IRR	12%

The economic results are presented for each case in Table 4; all results are presented for a 12% IRR. Carbon tax results are presented for the average natural gas price only, when applicable. The SRI results without HTGR integration assumed electricity is purchased at the 2010 average industrial price, \$67.90/MWe-hr. Results are presented graphically in Figure 2 and Figure 3.

Table 4. Syngas generation economic results.

	Natural Gas Price ($/MSCFD)	Syngas Price ($/MMBTU)	Carbon Tax ($/ton)	Product Price[5] ($/MMBTU)
	TCI			
Gasification w/o Sequestration	*$4,428,831,665*			
	N/A	9.80	50	13.48
			100	17.16
			150	20.83
			200	24.51
Gasification w/ Sequestration	*$4,503,718,539*			
	N/A	11.44	50	11.44
			100	11.44
			150	11.44
			200	11.44
HTGR Gasification	*$15,612,464,986*			
	N/A	22.06	50	22.11
			100	22.16
			150	22.20
			200	22.25
SMR	*$1,215,799,451*			
	4.50	7.42	50	9.27
	5.50	8.64	100	9.89
	12.00	16.55	150	10.52
			200	11.15
HTGR SMR	*$3,738,413,363*			
	4.50	9.19	50	10.21
	5.50	10.21	100	10.21
	12.00	16.79	150	10.21
			200	10.21
Gasification SMR w/o Sequestration	*$2,186,295,120*			
	4.50	8.33	50	10.44
	5.50	9.23	100	11.65
	12.00	15.09	150	12.86
			200	14.06
Gasification SMR w/ Sequestration	*$2,199,738,276*			
	4.50	8.54	50	10.21
	5.50	9.44	100	10.98
	12.00	15.30	150	11.75
			200	12.52

[5] Product price for the carbon tax calculated at the average natural gas price, when applicable.

Table 4. Syngas generation economic results.

HTGR Gasification SMR w/o Sequestration	*$5,816,734,002*			
	4.50	10.59	50	11.67
	5.50	11.24	100	12.11
	12.00	15.45	150	12.54
			200	12.98
HTGR Gasification SMR w/ Sequestration	*$5,879,403,543*			
	4.50	10.80	50	11.45
	5.50	11.45	100	11.45
	12.00	15.66	150	11.45
			200	11.45
SRI	*$1,711,918,230*			
	4.50	13.30	50	13.82
	5.50	13.82	100	13.82
	12.00	17.18	150	13.82
			200	13.82
HTGR SRI	*$10,078,695,338*			
	4.50	15.99	50	16.51
	5.50	16.51	100	16.51
	12.00	19.87	150	16.51
			200	16.51

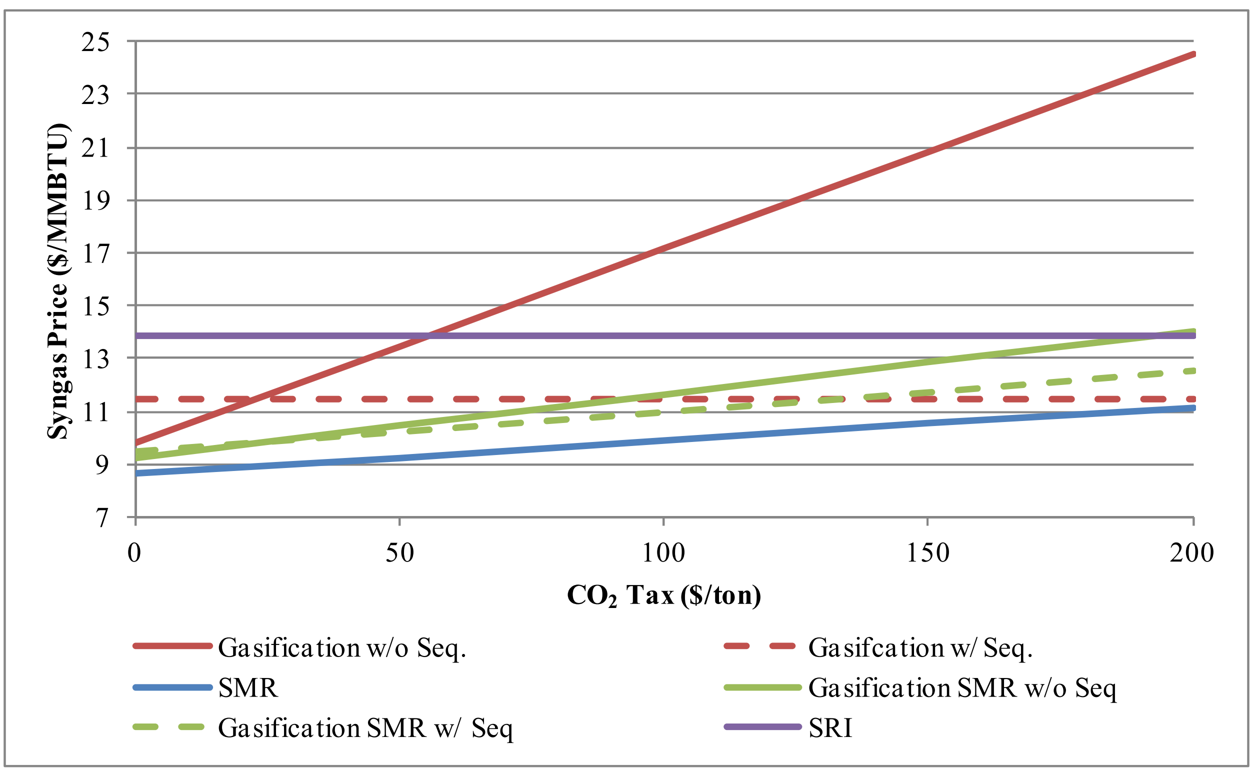

Figure 2. Carbon tax results, baseline cases.

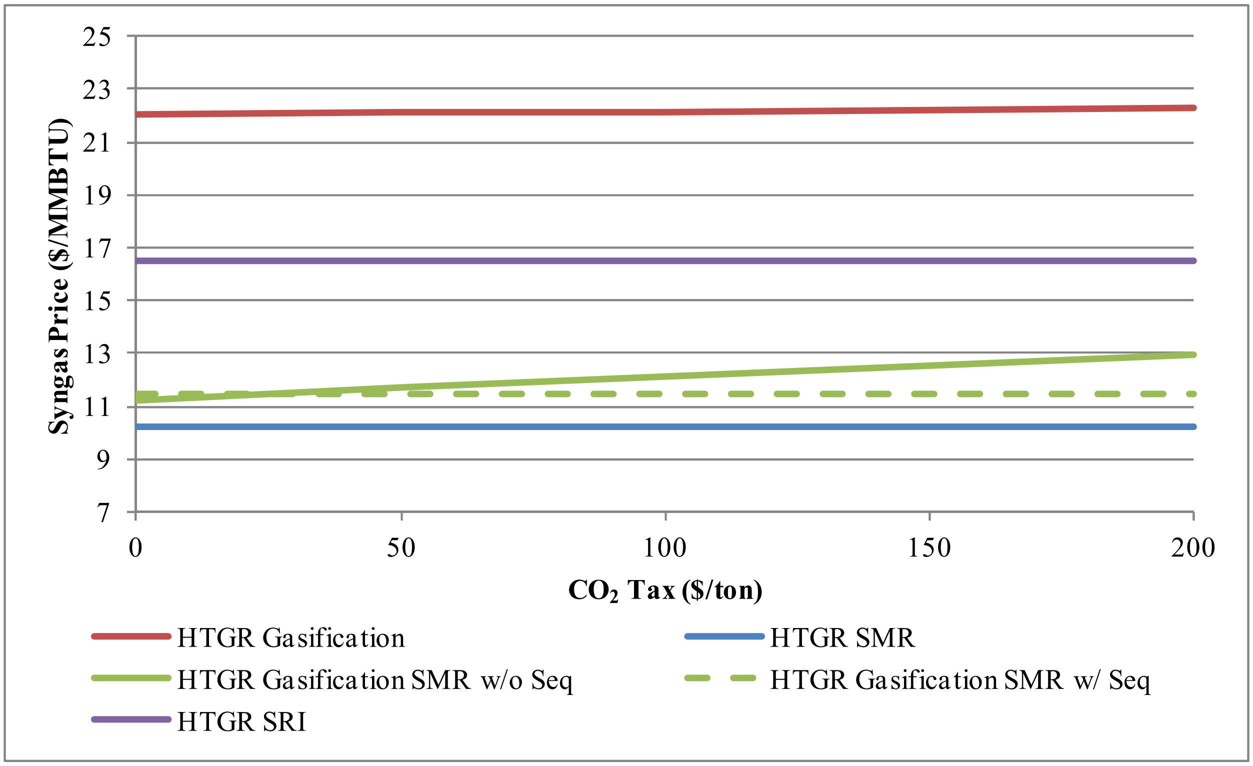

Figure 3. Carbon tax results, HTGR-integrated cases.

When compared to the other methods of syngas generation, it is apparent that the SRI process is less economically competitive. The baseline SRI process, which purchases power from the grid, requires a higher syngas selling price than all cases for all carbon taxes, excluding the gasification case without CO_2 sequestration, to achieve a 12% IRR. When the HTGR is integrated with the process, the SRI process requires a higher syngas selling price to achieve a 12% IRR than all cases for all carbon taxes, excluding the HTGR-integrated gasification case, which coincidentally requires even a larger electrical input than the SRI process.

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