Preliminary Techno-Economic Assessment of High Temperature Modular Reactor (HTMR-100) Deployment for South African Mining Applications

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1. Introduction

South Africa's mining sector depends heavily on reliable and affordable energy supplies to sustain production and economic competitiveness. However, persistent electricity supply challenges, together with increasing pressure to reduce greenhouse gas emissions, have intensified the need for reliable low-carbon energy alternatives for mining operations [1]. Small Modular Reactors (SMRs) have emerged as a potential option because of their enhanced safety features, modular construction, and capability to provide both electricity and non-electric energy products [2]. In particular, SMRs can support industrial applications requiring electricity, process heat, hydrogen production, and other forms of cogeneration [2,3,4]. The high temperature modular reactor (HTMR-100), a 100-MWth reactor concept under development in South Africa, is particularly relevant to such industrial applications. Its potential uses include electricity generation, industrial process heat, hydrogen production, and water treatment [3]. These characteristics make the HTMR-100 a potential energy option for South African mining operations, including remote sites where reliable electricity and industrial energy services are required. Previous studies have examined the techno-economic performance of nuclear-assisted hydrogen production, with particular emphasis on hydrogen production costs and system efficiency [5,6]. However, the deployment of an SMR-based hydrogen system in the mining sector requires consideration of not only economic performance but also broader factors such as radiation safety, emergency preparedness, regulatory readiness, workforce capability, project execution risks, and site-specific mining requirements [7,8]. Therefore, a comprehensive deployment decision cannot be based solely on hydrogen production cost. As the first phase of a broader risk-informed decision support framework, this study conducts a preliminary techno-economic assessment of HTMR-100-supported hydrogen production for South African mining applications. The International Atomic Energy Agency's hydrogen economic evaluation programme (HEEP) is employed to estimate hydrogen production costs under three deployment scenarios and to evaluate the effects of key economic parameters, including the discount rate and reactor capital cost [9]. The resulting economic indicators will provide quantitative inputs to a subsequent risk-informed multi-criteria decision analysis (MCDA). In the next phase, these economic results will be integrated with radiation safety, emergency preparedness, regulatory readiness, project execution risks, workforce readiness, and mining applicability to support a more comprehensive assessment of HTMR-100 deployment alternatives.

2. Methods and Results

The techno-economic assessment was performed using the IAEA's HEEP. The principal technical and economic input parameters are summarized in Table 1. The HTMR-100 was modelled with a thermal output of 100 MWth and an electrical output of 35 MWe per unit. The base-case economic assumptions included a 40-year operating life, a discount rate of 10%, an inflation rate of 5%, and an overnight capital cost (OCC) of ZAR 10 billion per reactor unit. The fuel-cycle parameters were based on publicly available HTMR-100 design data, with an initial fuel loading of approximately 1,379 kg and an annual fuel feed of 456.6 kg [3]. Three hydrogen production scenarios were evaluated by allocating 25, 50, and 75 MWth to hydrogen production, representing progressively increasing production capacities. As summarized in Table 2, the corresponding annual hydrogen production capacities were approximately 1.97, 3.94, and 5.92 million kg/yr, with electricity requirements of 82.38, 164.76, and 247.14 MWe, respectively. Based on the nominal electrical output of 35 MWe per HTMR-100 unit, these electricity requirements correspond to 3, 5, and 8 reactor units, respectively. For comparison under consistent transportation conditions, a pipeline distance of 200 km was assumed for all scenarios to represent the potential separation between hydrogen production facilities and mining end-use locations.

Table 1. Key assessment assumption

Parameter	Value
Discount Rate	10%
Inflation Rate	5%
Operating Life	40 Years
Thermal Rating	100 MWth/unit
Electricity Rating	35 MWe/unit
Initial Fuel Loading	1,379 kg/unit
Annual Fuel Feed	456.6 kg/unit
Overnight Capital Cost	ZAR 10 Billion

Table 2. Hydrogen scenarios

Scenario	Heat Allocated to Hydrogen (MWth)	Hydrogen Production (kg/yr)	Electricity Required (MWe)	HTMR-100 Units
1	25	1,972,350	82.38	3
2	50	3,944,700	164.76	5
3	75	5,917,050	247.14	8

The levelized hydrogen production costs calculated using HEEP are summarized in Table 3. The estimated cost decreased from ZAR 1,898.74/kg H_2 in Scenario 1 to ZAR 1,450.85/kg H_2 in Scenario 2 and ZAR 1,125.35/kg H_2 in Scenario 3. Thus, increasing annual hydrogen production from approximately 1.97 to 5.92 million kg resulted in a 40.7% reduction in the levelized hydrogen production cost. The results demonstrate a clear scale-related economic benefit under the assumptions adopted in this study. As hydrogen production capacity increased, the levelized contribution of reactor and associated infrastructure costs decreased relative to the total hydrogen output. Scenario 3 therefore achieved the lowest unit hydrogen production cost among the three cases evaluated, although it required the largest installed reactor capacity. This result indicates that the scale of hydrogen production and the corresponding number of HTMR-100 units are important factors in evaluating the economic feasibility of deployment for mining applications. The cost breakdown obtained from HEEP shows that nuclear power plant costs constitute the dominant component of the total hydrogen production cost in all three scenarios, accounting for approximately 85.9~89.1%. Hydrogen generation infrastructure contributed approximately 6.8~11.4%, while transportation and storage represented comparatively smaller shares. The predominance of nuclear power plant costs indicates that reactor capital investment and associated financing conditions are major determinants of overall hydrogen production economics. This finding is consistent with previous assessments of nuclear-assisted hydrogen production, which also identified reactor-related capital investment as a major contributor to the levelized cost of hydrogen [10]. The specific cost shares obtained in the present analysis reflect the HTMR-100 configuration and the economic assumptions applied in this study. Consequently, reductions in reactor capital cost and improvements in financing conditions could substantially enhance the economic competitiveness of HTMR-100-supported hydrogen production.

Table 3. Levelized hydrogen production cost

Scenario	Hydrogen Production (kg/yr)	Hydrogen Cost (ZAR / kg H_2)
Scenario 1	1,972,350	~1,898.74
Scenario 2	3,944,700	~1,450.85
Scenario 3	5,917,050	~1,125.35

A sensitivity analysis was conducted using Scenario 3 as the reference case, with a base hydrogen production cost of ZAR 1,125.35/kg H_2. The discount rate and reactor overnight capital cost (OCC) were varied independently to evaluate their effects on hydrogen production economics, as summarized in Table 4. Reducing the discount rate from the base value of 10% to 8% decreased the hydrogen production cost to ZAR 952.24/kg H_2, a reduction of approximately 15.4%, whereas increasing the discount rate to 12% raised the cost to ZAR 1,345.92/kg H_2, an increase of approximately 19.6%. Similarly, a 20% reduction in reactor OCC, from ZAR 10 billion to ZAR 8 billion per unit, decreased the hydrogen production cost to ZAR 953.72/kg H_2, while a 20% increase to ZAR 12 billion per unit raised the cost to ZAR 1,296.97/kg H_2. These results demonstrate that hydrogen production economics are highly sensitive to both financing conditions and reactor OCC. Within the ranges evaluated, changes in the discount rate had a slightly greater effect on the levelized hydrogen cost than equivalent ±20% changes in reactor OCC. Together with the cost breakdown results, the sensitivity analysis indicates that financing conditions and reactor capital investment are the primary economic drivers of HTMR-100-supported hydrogen production, highlighting their importance in assessing the economic viability of deployment for South African mining applications.

Table 4. Sensitivity analysis

Case	Hydrogen Cost (ZAR / kg H_2)
Base Case	1,125.35
Discount Rate = 8%	952.24
Discount Rate = 12%	1,345.92
Reactor OCC = ZAR 8 bn	953.72
Reactor OCC = ZAR 12 bn	1,296.97

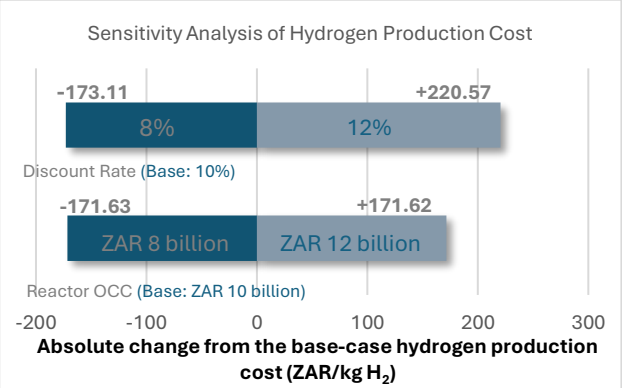


Fig. 1. Tornado diagram showing the absolute change in levelized hydrogen production cost resulting from variations in the discount rate and reactor overnight capital cost (OCC), relative to the base-case cost of ZAR 1,125.35/kg-H_2.

3. Conclusions

The results demonstrate that the economic performance of HTMR-100-supported hydrogen production improves with increasing production scale under the assumptions considered in this study. The levelized hydrogen production cost decreased from ZAR 1,898.74/kg H_2 in Scenario 1 to ZAR 1,125.35/kg H_2 in Scenario 3, corresponding to a reduction of approximately 40.7%. Nuclear power plant costs remained the dominant cost component, accounting for approximately 85.9~89.1% of

the total hydrogen production cost across the three scenarios. The sensitivity analysis further identified financing conditions and reactor OCC as the principal economic drivers. For Scenario 3, varying the discount rate from 8% to 12% resulted in hydrogen production costs ranging from ZAR 952.24 to 1,345.92/kg H_2, while a ±20% variation in reactor OCC resulted in costs ranging from ZAR 953.72 to 1,296.97/kg H_2. These results indicate that favorable financing conditions and reductions in reactor capital investment will be critical to improving the economic viability of HTMR-100-based hydrogen production for South African mining applications. Overall, this preliminary assessment provides a quantitative economic basis for evaluating HTMR-100 deployment alternatives. The economic indicators established in this study can subsequently be integrated with non-economic criteria within the proposed risk-informed multi-criteria decision framework, enabling a more comprehensive assessment of HTMR-100 deployment for South African mining operations.

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