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RESEARCH ARTICLE

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A LICENSING PLAN FOR COUPLING NUCLEAR–RENEWABLE HYBRID ENERGY SYSTEMS

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ABSTRACT

South Africa committed to reducing greenhouse gas emissions by 34% below "Business As Usual" levels by 2020 and 42% by 2025 at the Copenhagen climate change conference. However, global energy demand was projected to rise due to population and industrial growth, with energy usage expected to increase by 13% through 2040. In South Africa, a steady increase in electricity demand prompted the government to implement a new growth path (NGP), which prioritized job creation in all economic policies, including energy. To address the growing energy demand, an alternative energy source for combined heat and power was necessary, particularly for synthetic fuel production. The coupling of a high temperature reactor (HTR) with a chemical process plant could improve carbon and thermal efficiency, as seen in international organizations like the ARCHER (Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D) project. HTRs are still in their conceptual stages andaresuitable candidate forcouplingto an energy-intensiveindustrythat require process heat with sufficiently hightemperatures,with potential uses for NRHES (Nuclear-Renewable Hybrid Energy Systems). The South African team aimed to model the SASOL process, assess its financial viability, and develop a licensing plan.

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INTRODUCTION

In 2009, South Africa made a commitment to decrease greenhouse gas emissions by 34% below business-as-usual levels by 2020 and 42% by 2025 at the Copenhagen climate change conference. However, due to global population and industrial growth, energy demand was expected to increase, with electricity consumption projected to double by 2030. Economic growth in South Africa led to a steady increase in electricity demand, resulting in a reduction of Eskom's reserve generation capacity. The government's New Growth Path (NGP) prioritizes job creation in all sectors, including energy, communication, transport, water, and housing. This commitment to reducing greenhouse gas emissions and promoting job creation led to an investigation into alternative energy sources for synthetic fuel production, other than coal-fired energy. A High-Temperature Reactor (HTR) coupled with a chemical process plant, such as Sasol's coal-to-liquid (CTL) process, could potentially increase carbon and thermal efficiency. HTR technology is in its conceptual phase and is a suitable candidate for coupling to energy-intensive industries that require high-temperature process heat, with potential uses in Nuclear-Renewable Hybrid Energy Systems (NRHES). The licensing feasibility of this plan was critical, and the South African team modelled the Sasol process to demonstrate its financial viability.

Motivation for the study: In order to provide SASOL with combined heat and power (CHP) through HTR modules, a nuclear installation license is required. This license must be obtained prior to any nuclear activities, in accordance with section 20 of the National Nuclear Regulatory (NNR) Act of South Africa (NNR Act No. 47 of 1999). The NNR oversees all necessary license activities such as site assessment, design approval, manufacturing and construction authorization, operation, decontamination, and decommissioning. To evaluate the financial feasibility of introducing HTR energy to the SASOL CTL process, the SA team requires a quantifiable assessment of the time and cost associated with licensing this scenario in South Africa. HTR energy is still in the conceptual stage but is an ideal candidate for coupling with energy-intensive industries that require high-temperature process heat, with possible uses for NRHES. Therefore, to accurately measure the economic risk and delays caused by licensing, research must be conducted to formulate a licensing plan for coupling a nuclear energy source with a chemical process plant, using SASOL's Secunda facility as a case study.

Previous studies on nuclear technology: PBMR technology was expected to achieve the goals of safety, environmentally acceptance, efficiency, and energy production for high temperature to generate electricity and industrial process heat applications. In September 2003, PBMR Company had formulated the design concept of PBMR's layout in accordance with the requirements of the US Department of Energy (DoE). On two separate occasions in August 2003 and February 2004, both the conceptual layout and the design concept (i.e., on the technology) were presented to the DoE's technical review group. Shortly thereafter, a request for expressions of interest regarding the PBMR project was made to the DoE by Westinghouse Electric Company. PBMR technology was expected to achieve the goals of safety, environmentally acceptance, efficiency, and energy production for high temperature to generate electricity and industrial process heat applications. In September 2003, PBMR Company had formulated the design concept of PBMR's layout in accordance with the requirements of the US Department of Energy (DoE). On two separate occasions in August 2003 and February 2004, both the conceptual layout and the design concept (i.e., on the technology) were presented to the DoE's technical review group. Shortly thereafter, a request for expressions of interest regarding the PBMR project was made to the DoE by Westinghouse Electric Company. The ARCHER project extended the advanced European HTR technology to consortiums consisting of industry, technical support groups, R&D institutes, and universities, such as North-West in South Africa.

- Nuclear cogeneration unit coupled to industrial processes system integration assessment;
- R&D high temperature material; and
- Safety characteristics of critical primary and coupled system.

Figure shows an example of a basic configuration of a commercial process heat cogeneration plant under investigation. Lamarsh and Baratta describes a HTR as a helium-cooled, graphite-moderated, thermal reactor. The helium is used as the coolant as illustrated by the red loops as it is far more inert than CO_2. The blue loops present the water and steam, while the brown loops represent the processed water and steam or non- nuclear process fluid. Several possible coupling schemes exist for introducing the nuclear process heat to SASOL. The most appropriate method is through steam for the end-user processes and heat transfer technology. The HTR reactor is known for its inherent safety features (non-melting core and passive safety), which make it a suitable candidate for coupling to an energy-intensive industry. Energy-intensive processes in chemical process plants require process heat with sufficiently high temperatures (i.e., greater than 700°C) to support chemical production processes. Both the HTR co-generation plant and the energy-intensive installation requiring process heat to operate together as an integrated complex. According to the European nuclear energy forum, it could be recommended to couple a new HTR cogeneration plant close to an existing energy-intensive user (e.g., such as SASOL).

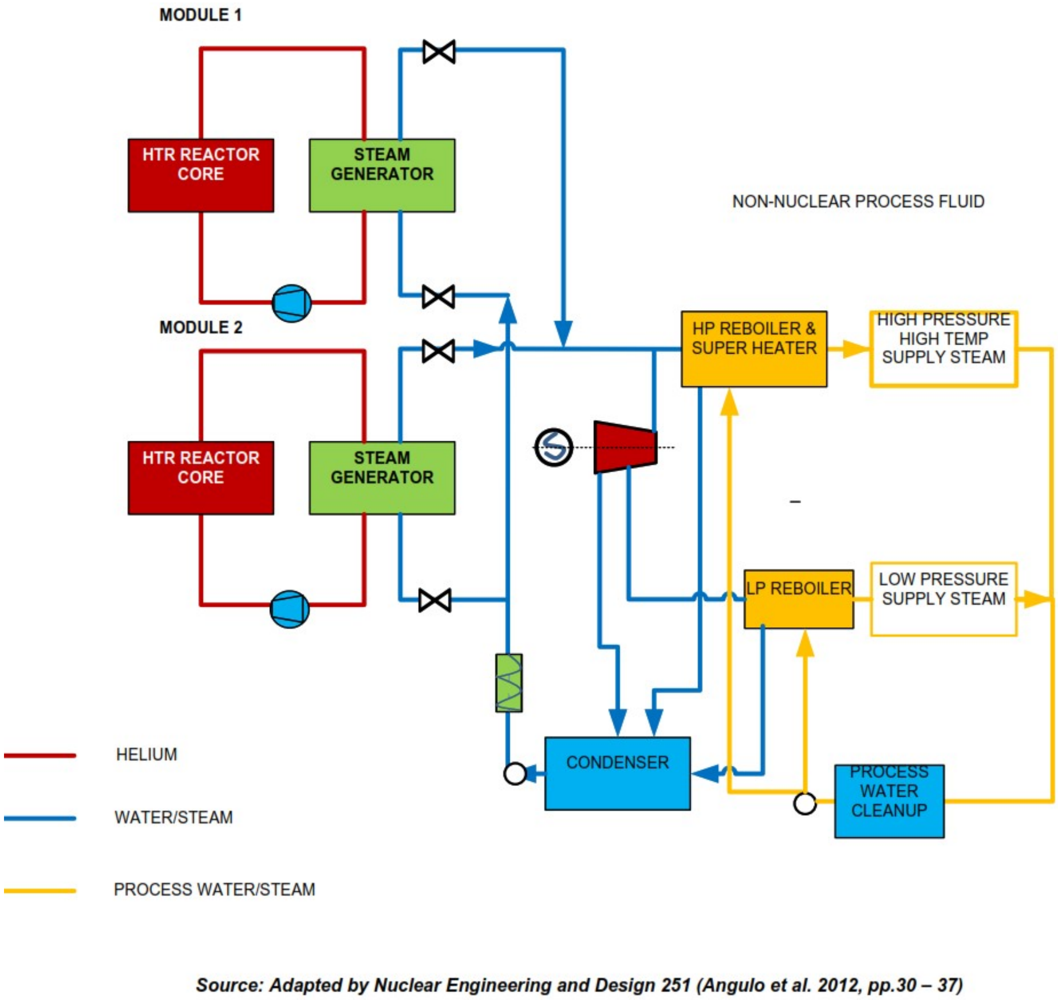
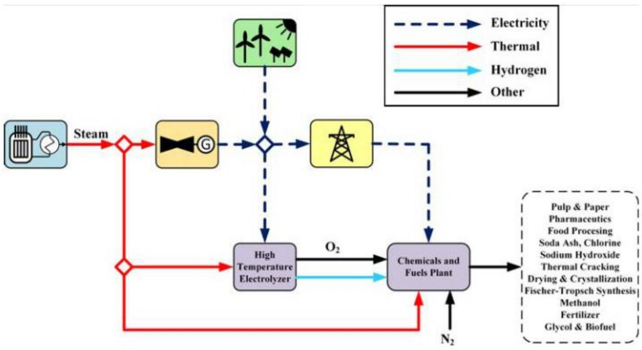


Figure 1. Steam Coupling for Nuclear Coal-To-Liquid (NCTL) Production Plant

All partners collectively propose efforts to compose the following:

- Developments of coupling components;
- HTR fuel including fuel back-end R&D;
- Nuclear cogeneration communication, knowledge management and training.

Current Studies on Nuclear Technology: The increasing use of renewable energy sources in the global energy mix is not only economically motivated, but also supported by social development goals. As a result, many countries have provided political backing and funding for this transition. Despite the challenges posed by the integration of variable renewables, this shift presents opportunities for sustainable development. One promising approach is to combine nuclear and renewable energy resources to achieve mutually beneficial results. This strategy addresses the intermittency of renewable sources by creating a more balanced and inclusive energy system that is cost-effective, secure, eco-friendly and robust. A range of potential uses for NRHES within the chemical industry are depicted in Figure . All technologies are currently in commercial use, although plans to implement them in NPPs are still in their conceptual stages such as HTR reactors, which are suitable candidate for coupling to an energy-intensive industry that require process heat with sufficiently high temperatures (i.e., greater than 700°C)



Source: Nuclear–renewable hybrid energy systems, (IAEA) *2022*

Figure 2. Example of Nuclear-Renewable Hybrid Energy System (NRHES) for Production Plant

Before implementing a new energy system, several factors must be considered. These encompass a variety of elements, including financial and technical aspects such as technoeconomic analysis. This analysis is used to evaluate the technical and economic feasibility of proposed energy systems. Initially, steady state modelling tools are utilized to determine energy balances within the system. More detailed dynamic analyses follow, focusing on real-time energy flows to optimize the system's configuration, component and subsystem sizing, and energy dispatch. These analyses must adhere to established technical constraints while striving for an optimization goal, such as maximum profitability or minimum levelized cost of energy and several licensing issues that come with the coupling of these systems.

International Licensing Guide*:* IAEA shows a typical process for licensing during the life-cycle of the nuclear installation (i.e. siting, inter alia, release from the safety authority). Primary stages within the IAEA's licensing process are illustrated in Figure 3.

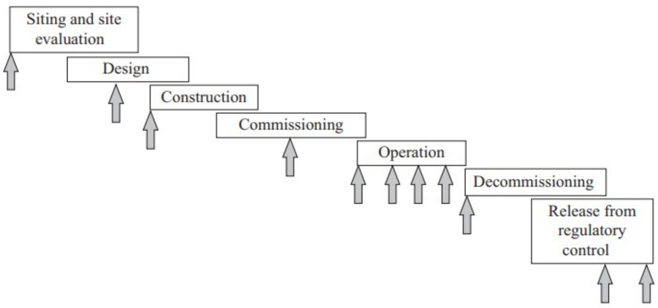


Figure 3. Steps during the Lifecycle of a Nuclear Installation

"Hold points" are indicated by the upward arrows was set by the safety authority and national legislation, to ensure that the risks to the environment are controlled. The steps mentioned above may be separated into several sub-steps. Similarly, it may be combined to smooth the process of licensing. The licensee may combine the license (i.e. combining construction and operation), which may also provide more certainty in the process when licensing, as in the case of a nuclear installation license. Seven (7) out of ten (10) countries offer at least two licensing steps (e.g. construction and operating licenses) while others sometimes offer up to four licensing steps. The United Kingdom has a one-step licensing process while the United State and South Africa offer both options (i.e., one-step or multi-step) and are relevant to the primary aim of the research study. Pre-construction, siting and site evaluation were the most prevalent, which required expertise such as project managers, geologists, seismologist, meteorologists, hydrologists, environmental project managers and civil engineers. Similarly, for reviewing the basic design, staff required by the safety authority included electrical, nuclear, structural, civil, mechanical, chemical and material engineers as well as project managers. From previous study, it was noteworthy that the average regulatory reviews will take three (3) years from beginning to the start of construction from an international perspective. By the whole, the regulatory review process will take up to eight (8) years in some cases. Resources required are substantial when licensing. The overall funding requirements were estimated at ZAR 918,599,904.00 in 2013 value for the overall licensing of the NCTL Production Plant. Currently, the overall funding requirements is estimated at ZAR 1 515 313 773.68 in 2023 value for the licensing of the NRHES Production Plant with an overall timeline estimated at 8 years as suggested by international best practise[1].

Recommendations in respect coupling nuclear–renewable hybrid energy systems

Based on the outcomes current research, six (6) recommendations are outlined in respect to new paradigm of NRHES.

- To solicit inputs by the NNR and agree on the overall licensing of the NRHES Production Plant.
- To solicit inputs by the NNR and agree on the overall licensing of the NRHES.
- To agree on how to apply for multiple NILs for construction on a common site after being granted multiple NISLs and completion of the public participation process for inclusion of the new paradigm of NRHES.
- Prior to implementing a new paradigm, perform a technoeconomic analysis on the viability of proposed energy systems.
- To agree on typical timeline for review for each NRHES under consideration.
- Determine whether the overall licensing of the NRHES would be comparable to NCTL.

CONCLUSION

The research successfully achieved its objectives through meticulous planning and effective resource management. The chosen bottom-up approach and activity-based cost estimates proved to be effective in estimating the required funding and timelines for the licensing process. The estimated timeline for the licensing of the NRHES Production Plant is 8 years in accordance with international best practices. The estimated funding requirement for the licensing process is estimated at ZAR 1 515 313 773.68 in 2023 value. The research findings will be valuable in informing decision-making on the licensing of nuclear energy sources coupled to chemical process plants, especially in South Africa.

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