

# Prospects for the development of hydrogen energy: technologies of production, storage, and application

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## Introduction

Hydrogen energy is currently regarded as one of the most promising directions in the development of modern energy systems. This is driven by the potential of hydrogen to serve as an environmentally friendly energy carrier, as well as by its broad applicability in industry, transportation, and energy systems. The combination of rapid global population growth and expanding economic activity has led to a significant rise in energy demand over recent decades.

The objective of this study is to develop a fundamental dynamic model of the HES -10×2 electrolysis unit implemented in the MATLAB/Simulink environment to evaluate key operating parameters, including voltage, power consumption, hydrogen and oxygen production rates, and temperature dynamics over time [1], [4], [5]. The combination of rapid global population growth and expanding economic activity has led to a significant rise in energy demand over recent decades. The objective of this study is to develop a fundamental dynamic model of the HES -10×2 electrolysis unit implemented in the MATLAB/Simulink environment to evaluate key operating parameters, including voltage, power consumption, hydrogen and oxygen

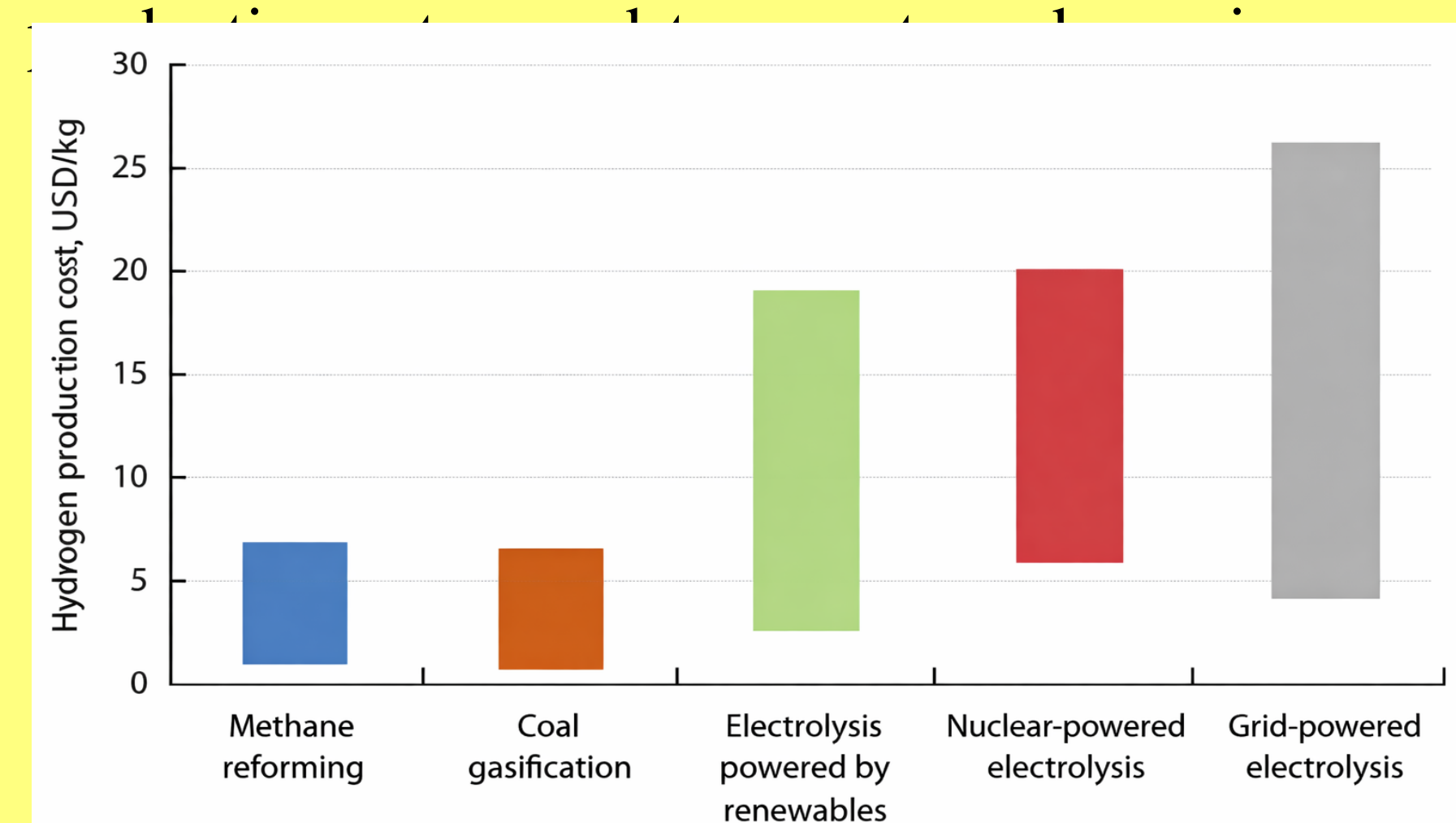


Fig.1. Ranges of production costs worldwide for hydrogen by different methods.

## Experimental setup

The main directions for the development of the global low-carbon hydrogen market include replacing high-carbon-footprint hydrogen with more environmentally friendly alternatives, building infrastructure for its transportation, and introducing low-carbon hydrogen into sectors where it has not been used previously. [3], [6], [8].

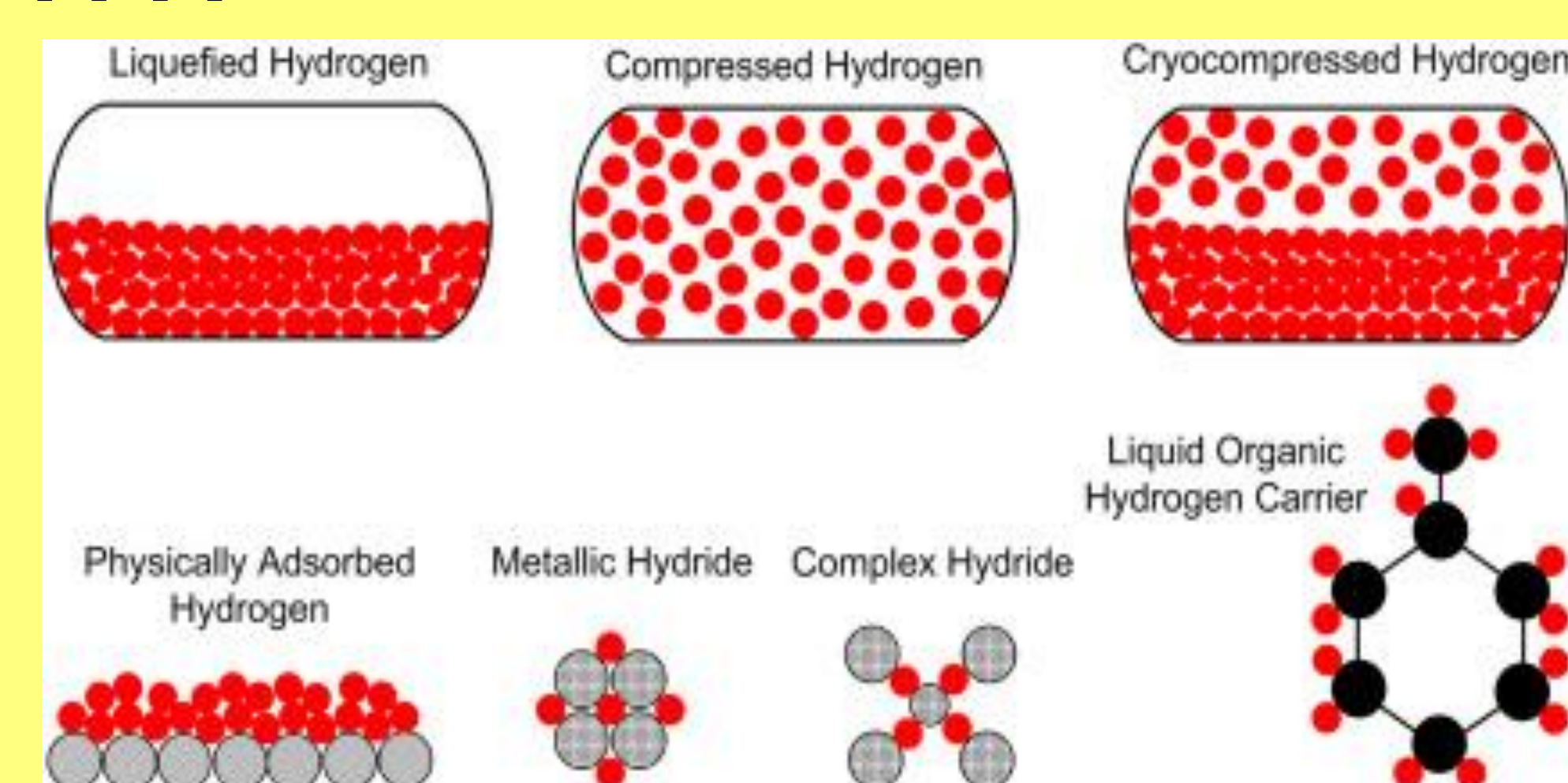


Fig.2. Hydrogen Storage Methods Comparison

Figure 2 presents a schematic comparison of the main hydrogen storage methods, categorized into physical and material-based (solid-state and chemical) approaches. The illustration highlights the differences in hydrogen distribution and storage mechanisms for each method. [1], [2].

The upper part of the figure depicts physical storage techniques. Liquefied hydrogen is shown as a dense layer of particles at the bottom of the container, representing high volumetric density achieved under cryogenic conditions. Compressed hydrogen is illustrated by uniformly distributed molecules throughout the vessel, corresponding to high-pressure gaseous storage.

Cryo-compressed hydrogen combines both features, with partially dense and partially dispersed molecules, indicating a hybrid approach that utilizes both low temperature and elevated pressure. The lower part of the figure illustrates material-based storage methods. Physically adsorbed hydrogen is represented by molecules attached to the surface of a solid material, reflecting weak intermolecular interactions. Metallic hydrides are shown as hydrogen atoms embedded within a metal lattice structure, indicating absorption-based storage

## Experiment

Hydrogen storage and transportation methods are divided into physical and chemical ones. Physical methods involve the storage and transportation of pure hydrogen in gaseous or liquid form. Chemical methods are based on binding hydrogen with other substances, resulting in the formation of metal hydrides, non-metal hydrides, or its retention within the structure of clathrate hydrates. In addition, chemical transportation methods include the movement of hydrogen in the form of organic compounds, such as methane-hydrogen mixtures, methanol, and ammonia, with subsequent hydrogen release directly at the consumer's site [5], [7].

At the initial stage of the study, a basic computational model of the HES-10×2 electrolysis unit was developed in the MATLAB/Simulink environment. The model was constructed as a generalized dynamic scheme incorporating the main subsystems required for calculating the electrical and thermal parameters of the unit.

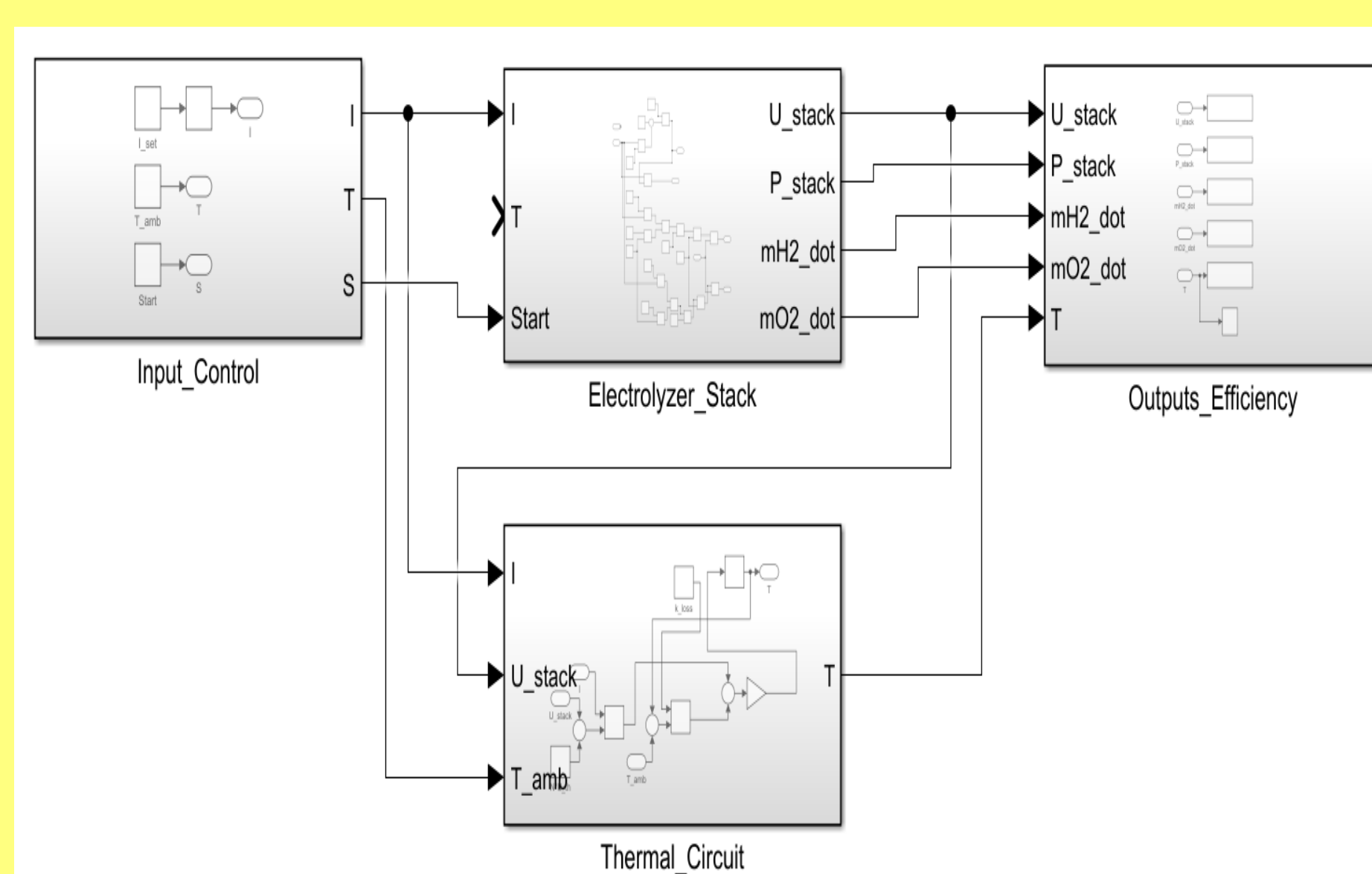


Fig. 3. Block diagram of the basic computational model of the HES-10×2 electrolysis unit in the MATLAB/Simulink environment.

## Results

The Input\_Control subsystem was used to define the initial operating conditions of the model. It specified the operating current of the unit, the ambient temperature, and the start signal. At the initial stage of the simulation, the following values were assumed: current of 200 A, ambient temperature of 25 °C, and start signal equal to 1.

The Electrolyzer\_Stack subsystem constituted the core computational module of the model. It was used to evaluate the system voltage, power consumption, as well as the hydrogen and oxygen mass flow rates. The voltage of an individual cell was estimated using a simplified formulation incorporating the reversible voltage and ohmic losses. The overall stack voltage was determined by accounting for the total number of cells. The power consumption was calculated as the product of voltage and current. The hydrogen and oxygen generation rates were evaluated based on Faraday's law of electrolysis.

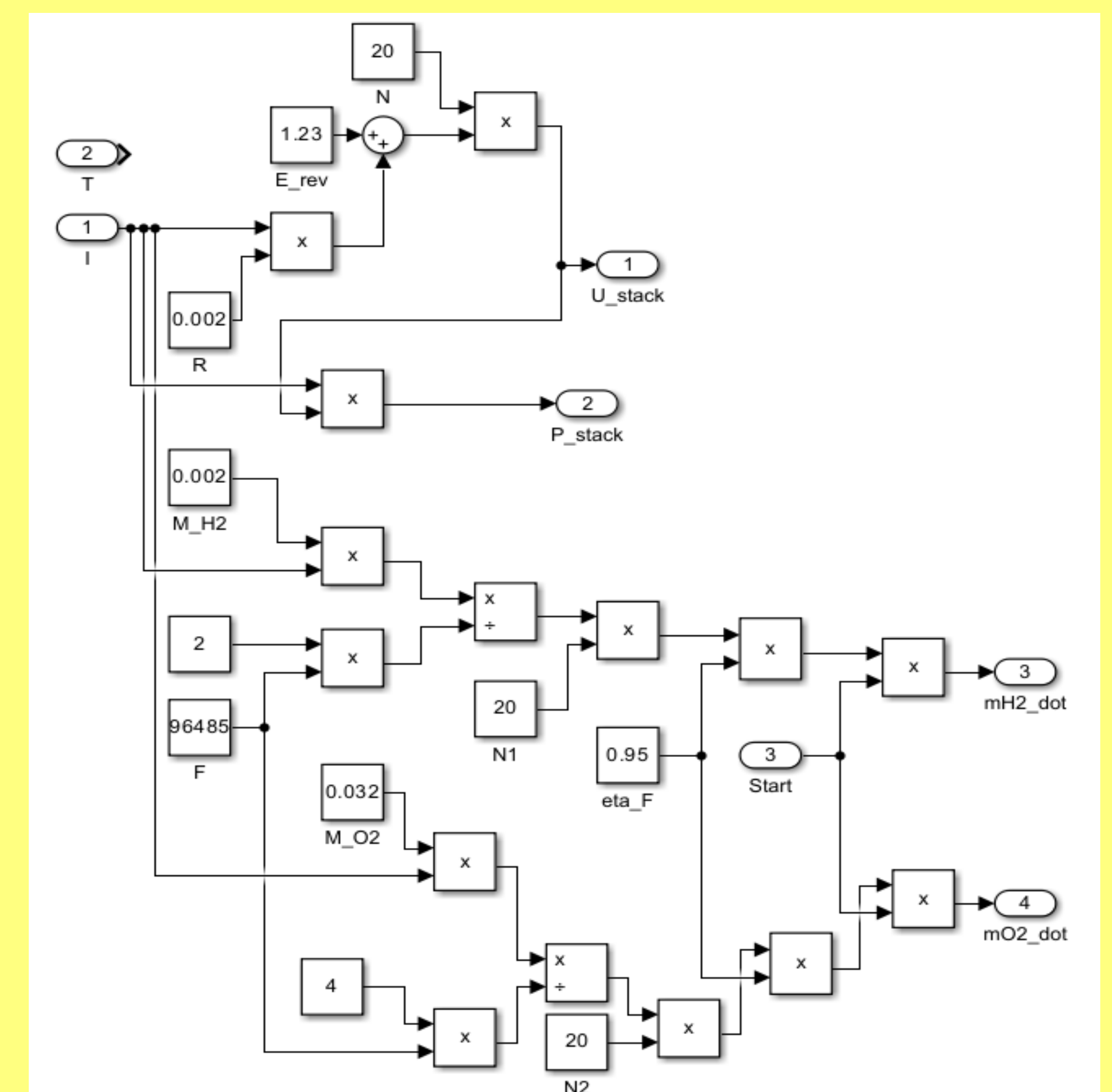


Fig. 4. Electrolyzer\_Stack Subsystem for Calculating Electrical Parameters and Electrolysis Product Output.

The Outputs\_Efficiency subsystem was designed for the visualization and analysis of simulation results. It provided real-time display of key calculated parameters, including system voltage, power consumption, hydrogen and oxygen mass flow rates, and temperature evolution. Numerical indicators were combined with graphical visualization tools to enable a detailed assessment of the system behavior. In particular, the temperature profiles allowed the evaluation of both transient thermal dynamics and steady-state operating conditions of the system.

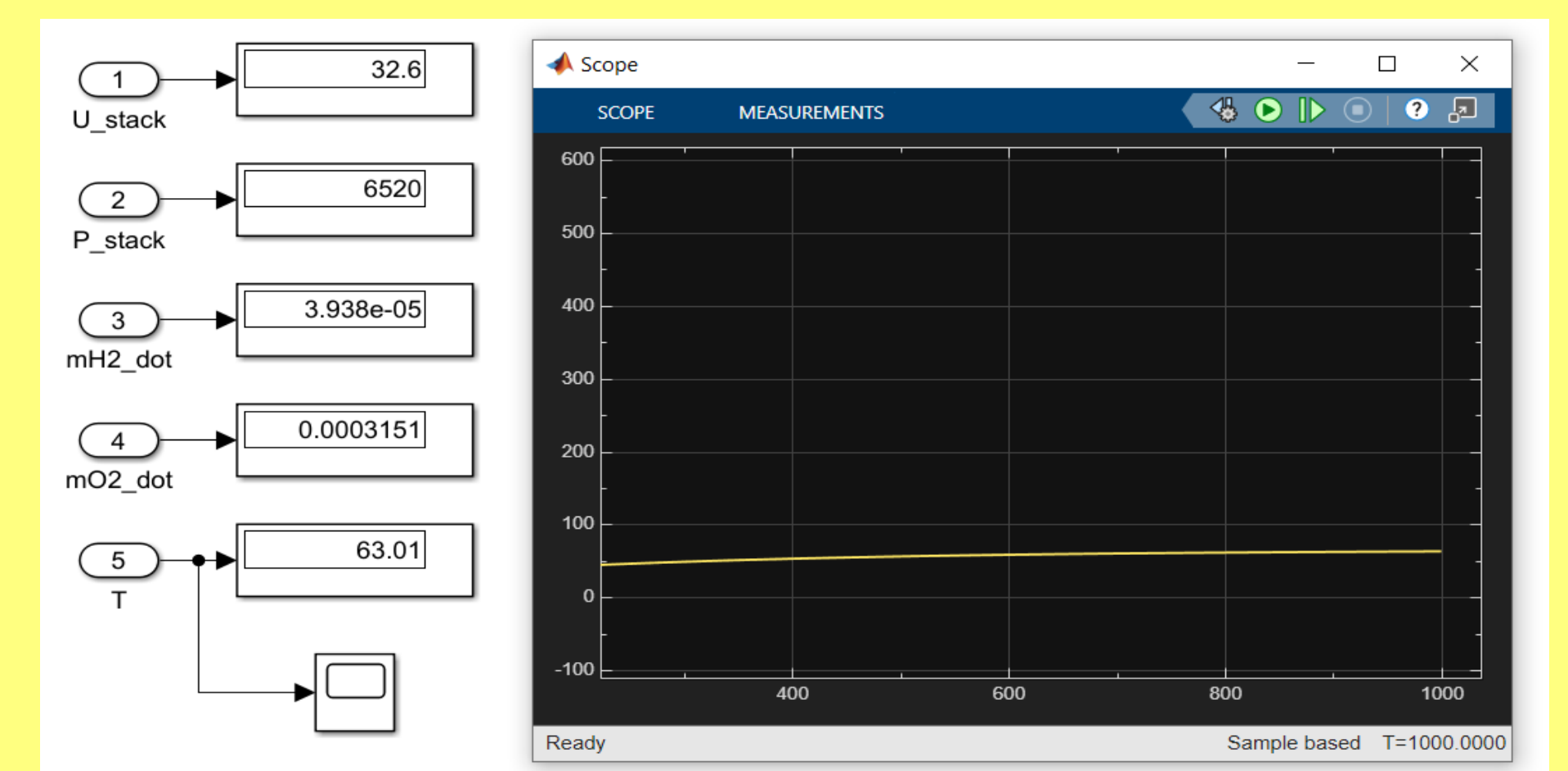


Fig.5. Outputs\_Efficiency Subsystem and Transient Temperature Response of the SEU-10×2 Electrolysis Unit

## Conclusions

In this study, a basic dynamic model of the HES-10×2 electrolysis unit was developed using the MATLAB/Simulink environment [10-11]. The proposed model allows for the estimation of key system parameters, including voltage, power consumption, hydrogen and oxygen mass flow rates, and temperature dynamics over time. The obtained results validate the effectiveness of the proposed model structure and confirm its suitability for preliminary analysis of electrolysis unit operating regimes. Future work will focus on extending the model by incorporating additional loss mechanisms, detailed process flow representations, and real operational data to improve its accuracy and predictive capability. [10], [12], [18].

## References

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