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INF FACULTY OF COMPUTER SCIENCE

VST FACULTY OF PROCESS AND SYSTEMS ENGINEERING

Visualization of Process Engineering Applications

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Report on the Application: H2H

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1 Introduction

1.1 Goals

The goal of our project is to create an application-based approach to understand and visualize the end-to-end process of green hydrogen generation using wind energy and its end application. This would create a platform to understand the macro-scale process components and enable user interactivity by changing a set of parameters depicting its effect on the process output.

The objective of the application is to:

- Visualize the process of Green Hydrogen using process component models.
- Educate and illuminate the components involved in the production of green hydrogen to children and people with no previous knowledge.
- Numerical Depiction of Hydrogen production and its dependence on wind speeds.

1.2 Project outline

This project is a windows-based application focusing on the industrial-scale visualization of the green hydrogen technology starting from electricity from wind energy, using the electricity generated for electrolysis of water, hydrogen production, and storage till the end user application of hydrogen as a fuel. Hydrogen as a fuel is used here in a bus powered by fuel cells. The main objective is to provide a user with a basic understanding of each individual component and its role in green hydrogen production using electrolysis. This app provides a relevant textual technical description of each process and its role in the overall process along with a graphical representation of specific components.

1.3 Process description

1.3.1 Introduction

Decarbonization of the global economy is one of the most important challenges today. The solution to this challenge is to consistently expand renewable energy sources as well as integrate renewables in developed industry, energy, and mobility infrastructures with Power to X solutions using green hydrogen. In this scenario, the green hydrogen is generated from Renewable energy (Wind energy) using PEM electrolysis which is an important contribution to the global energy transition.

1.3.2 Process layout

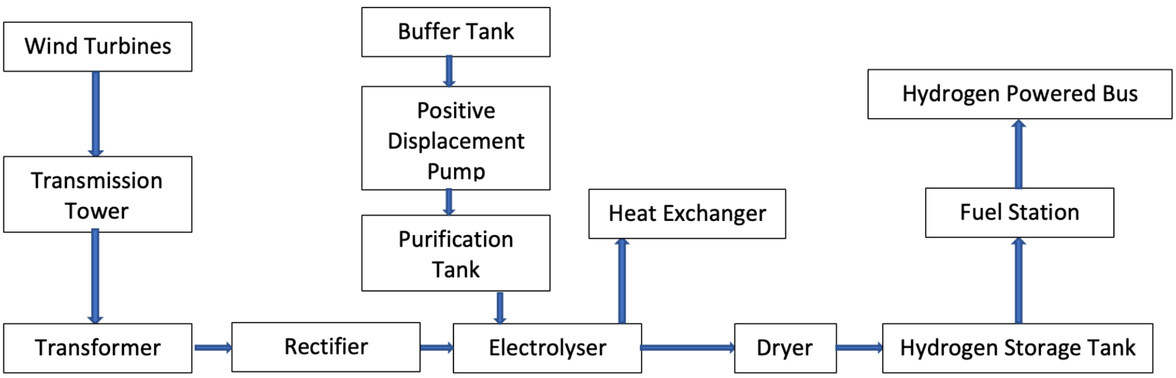

Image 1: Process layout

1.3.3 Process explanation

The whole process is divided into three processes for better explanation.

A. Electricity generation
Electricity is generated from wind turbines with wind energy as the input. The generated electricity from the turbines is transmitted to the transformer with the help of transmission towers.

B. Hydrogen Generation
The electrolyzer is provided with two inputs: Water supply and electricity. The water is first stored in a buffer tank and a steady water supply is pumped to the purification tank. The output from the purification tank is ready as the input for the electrolyzer. The electricity input from the rectifier to the electrolyzer helps in splitting the water

molecules into Hydrogen and Oxygen. Since the visualization focuses on the Hydrogen cycle, oxygen gas is neglected.

C. Hydrogen storage and Utilization
Hydrogen generated from the electrolyzer is dried in a dryer and stored in a hydrogen storage tank before sending it to the fuel station. The fuel is utilized by the hydrogen-powered bus at the fuel station.

1.3.4 State of the Art (Engineering)

- Fluctuations in the voltage are observed in the electricity produced from the wind turbines. A transformer is used to regulate the voltage output. To supply a steady voltage of 1500V a three-phase transformer is used. The transformer's input is connected to the primary coils, then using the principle of Electromagnetic Induction the concentric secondary coils generate the required Voltage as the output.
- The electrolyzer works on direct current whereas the output from the transformer is Alternating current, a rectifier is used to convert Alternating current to Direct current
- During the electrolysis process, a large amount of heat is produced. With the help of a heat exchanger, the waste heat from Electrolyser can be recovered or reused to desalinate water, or for other sustainable purposes, such as district heating. Using the waste heat from the electrolyzer increases the overall efficiency of the green hydrogen production plant.
- The produced hydrogen gas consists of moisture, the moisture can be removed with the help of a Dryer.

1.4 Process Components

The components involved in this process are

- **Wind Turbines:** Wind turbines are the devices that convert the kinetic energy of wind into electrical energy. The wind rotates the blades of the wind turbine which is connected to a Generator to produce electricity.
- **Transmission towers:** Transmission towers are tall structures that carry the high voltage current from the generation sources to the substations.
- **Transformer:** The transformer transfers the electric energy from one alternating current circuit to one or more circuits, either by stepping up or stepping down the voltage.
- **Rectifier:** Rectifier is the device that converts Alternating Current into Direct Current
- **PEM Electrolyser:** An electrolyzer is a setup that is used to extract hydrogen and oxygen from water using electricity.

    1. Water reacts at the anode to form oxygen and positively charged hydrogen ions (protons).
    2. The electrons flow through an external circuit and the hydrogen ions selectively move across the PEM to the cathode.

3. At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas.

- **Water Purification tank:** The water from the source consists of impurities and is filtered and treated chemically to make soft water that is free of ions.
- **Positive Displacement Pump:** A positive displacement pump moves a fluid by repeatedly enclosing a fixed volume, with the aid of seals or valves, and moving it mechanically through the system. The pumping action is cyclic and can be driven by pistons, screws, or gears.
- **Plate Heat Exchanger:** A heat exchanger is a system where the heat is transferred from hot fluid to other fluids by means of convection.
- **Buffer Tank:** The buffer tank is the device that is used to regulate the constant supply of water according to the requirement.
- **Hydrogen Storage Tank:** This device is used to store the produced hydrogen before it is utilized for further use.
- **Dryer:** The dryer is used to reduce the moisture content in the generated hydrogen gas.
- **Fuel station:** The fuel station is a setup where the stored hydrogen gas is distributed or supplied to automobiles as fuel.

1.5 Formulae Used

Electricity is generated from Wind Energy.
In the application, the power generated from wind energy is calculated by:

$$P = \left(\frac{\pi}{2}\right) * r^2 * v^3 * \rho * \eta$$

Equation 2-1

where,
P= Power Output (W)
v=Velocity of Wind(m/s)
and the considerations for calculations are taken to be
r=Radius of the wind Blade (50m)
ρ=Density of Air(1.2kg/m^3)
η= Efficiency Factor (35%)
The AC electricity produced by the windmills is sent to transformers and rectifier for the supply of DC Current at a constant voltage of 1500V to the electrolyzer.

The Operational Current to the electrolyzer is calculated by:

$$I = P/V$$

Equation 2-2

where,

I=Operational Current (Amp)
P= Power Output (W)
V=Voltage (Volts)

The relation between Operational Current and Hydrogen Output is given by the Faraday Equation (Petronilla Fragiacomo, 2020):

$$N \cdot I = \dot{m}(H2) \frac{Z \cdot F}{\eta F \cdot W\ (H2)}$$

Equation 2-3

Were,
N=Number of Cells
I=Operational Current
$\dot{m}(H2)$=Hydrogen Mass Flow Rate (Kg/Sec)
Z=Number of Electrons in the reaction [2]
$\eta F_{=}$ Faraday's Efficiency [99%]
F₌Faraday constant, 96,485,000 [Coulomb/kmol]
M.W(H2) =Molecular Weight of Hydrogen Molecule [2.016 kg/kmol]

Amount of water consumed (HYDROGENICS, 2018):
For the process of hydrogen production using water electrolysis, deionized water is used. The usage of deionized water saves energy and is economically desirable over tap water. Furthermore, it reduces fouling and increases the life of the electrolyzer. The water demand in commercial electrolyzers per kilogram of hydrogen generated is 11 Liters of Deionized Water.

2 User Documentation

This section describes general requirements, how-to guides, and how to use your application on Windows. This section helps users navigate within the application, and understand the scene and features with detailed explanations.

2.1 Minimum System Requirements

The application is compatible with most Windows devices meeting the minimum system requirements. The recommended system requirements for Unity3D are described below:

Minimum requirements	**Windows**
Operating system version	Windows 7 (SP1+) and Windows 10, 64-bit versions only
CPU	X64 architecture with SSE2 instruction set support
Graphics API	DX10, DX11, and DX12-capable GPUs

2.2 Installation of the application

The main application is compressed for efficient storage and transfer which can be extracted to unpack all the files. Then the .exe file can be used to open and run the application.

2.3 Scene Description

This section mainly defines the scenes and how the user can move through the environment to look around the application.

2.3.1 Menu Scene

When the user opens the application, a menu screen with choices is displayed which are starting the main scene, settings to change volume, credits, or exit the application.

Image 2: Main scene

2.3.2 Starting the application

When the user clicks on the start button they are taken to the next scene which shows the controls that can be used to move around the environment.

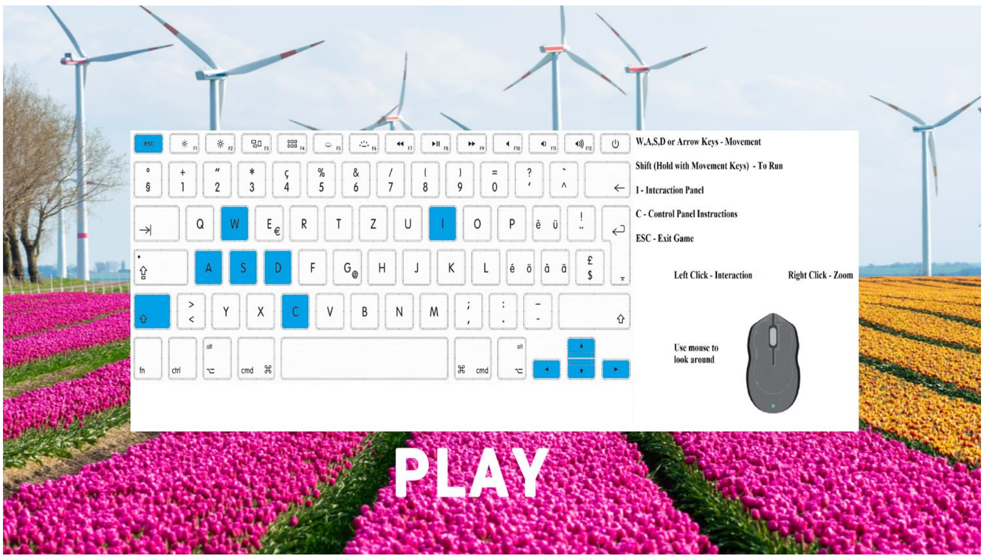

Image 3: Instructions panel

The controls include W, A, S, D, and the Arrow keys to move, “Shift” to run, pressing “I” for the information panel, “C” to enter control panel instructions, “ESC” for returning to the main menu and using the mouse to look around. Then the user needs to click the “PLAY” button on the screen to move to the process scene.

2.3.3 Process scene

There are three processes shown in the main scene. The first process shows electricity generation from renewable sources, the second process shows water to hydrogen production and the final process shows a use case of hydrogen as fuel.

It starts with the user on top of a block where they can see all three processes parallely. Then the user can move around and get close to each process and see the components in detail.

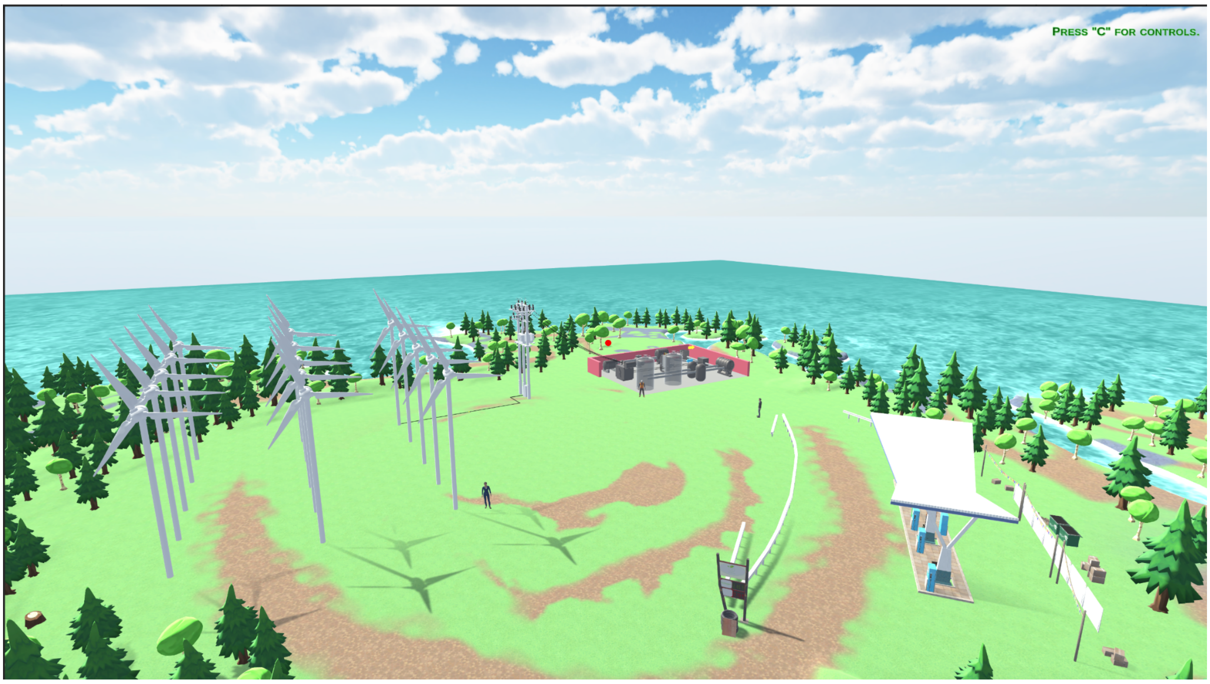

Image 4: Starting scene

2.4 Interactions within scene

2.4.1 Interaction

This section describes how the user can interact with the objects in the application and the changes made due to the interaction.

2.4.1.1 Interaction with characters

There are three characters describing each of the processes with which the user can interact by clicking on the character.

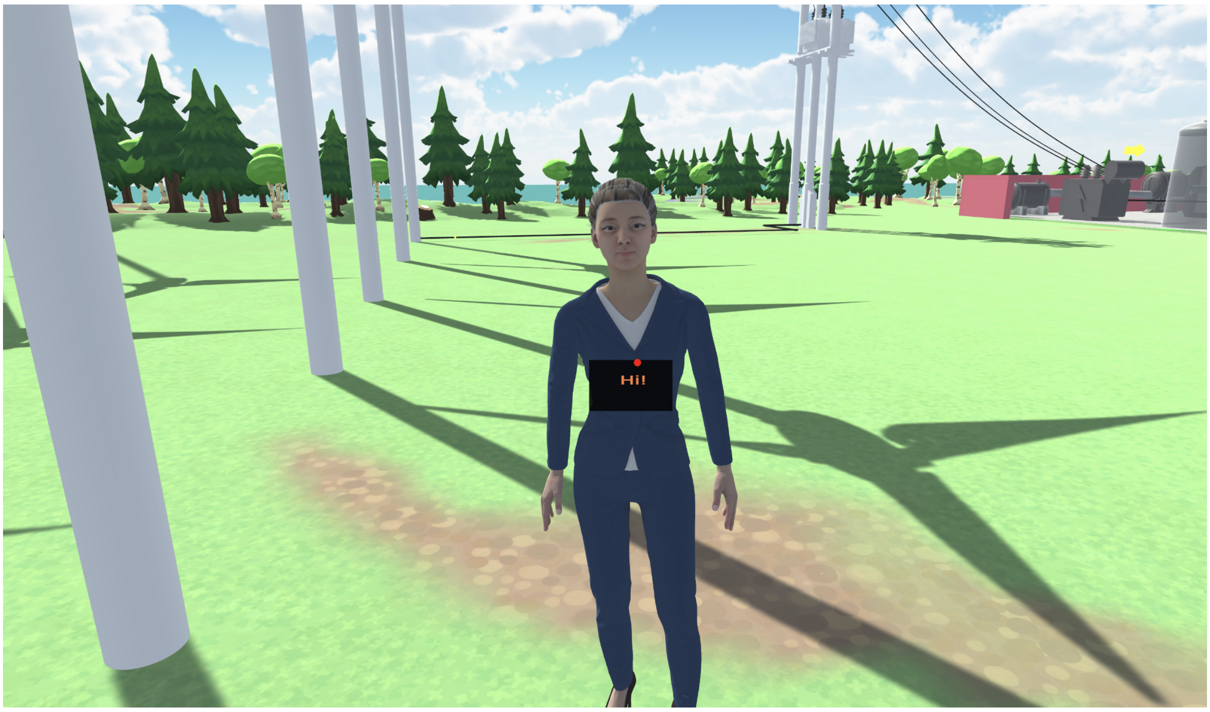

Image 5: Initial interaction with a character

The character detects the user when the pointer is pointing at them. When the user is detected the character shows a pop-up saying "HI!"

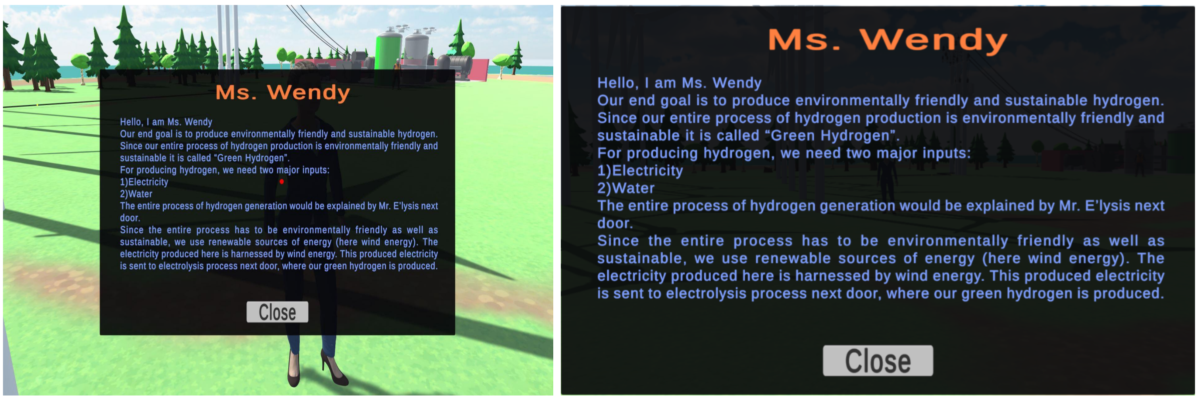

Image 6: Process descriptions

After the user has clicked on the character another pop-up shows describing the process in detail.

2.4.1.2 Interaction with components

The user can interact with most of the components in process 2. When the user is pointing at an object it gets highlighted to show that interaction can be made. The user can then click on the component to get more descriptions about the component.

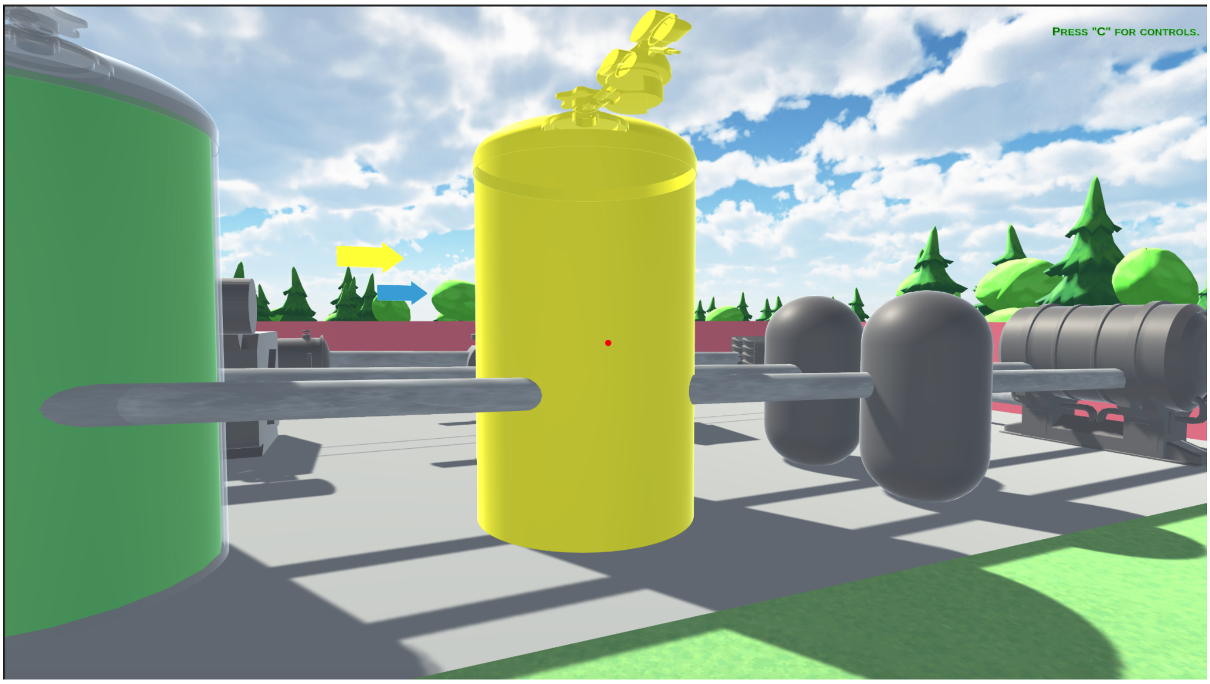

Image 7: Hydrogen tank

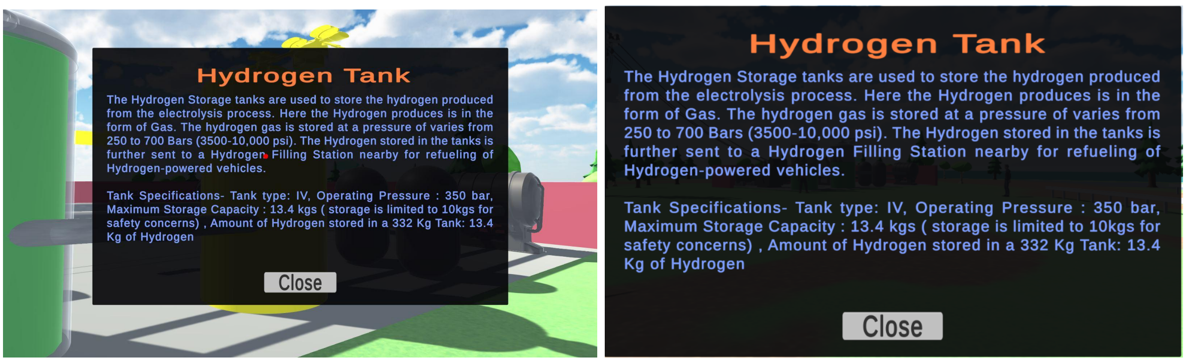

Image 8: Hydrogen tank - description

2.4.2 Information Panel

The user can access the information panel using the "I" key on the keyboard. It brings up the information panel which shows some statistics about the processes and a slider where the user can choose the wind speed to change some of the animations accordingly.

Image 9: Information panel

2.4.3 Role of the fuel station and bus

The generated hydrogen is stored in temporary tanks on the plant floor, then using underground pipes it is transported to this pumping station where the hydrogen is stored in pressurized vessels. The hydrogen is then pumped into the hydrogen-powered bus which would take you around this self-sustaining island. We hope this process is adapted more rapidly and widely around the world so that we can reduce the dependency on fossil fuels and turn this world into a much greener and cleaner place for our future generations to live in.

Image 10: Fuel station and bus

3 Developer Documentation

3.1 Tools used

Unity and C# - The application was developed using Unity3D version 2021.3.1f1. Unity 3D is a cross-platform game engine, such that we have support for both Windows and Mac. The scripts were written in C# using Visual Studio Code. We maintained code in Visual Studio Code Version 1.65.2.

Blender - We used Blender to model the components as it was easier to export the model to .fbx format which is the preferred format in Unity3D.

GitLab - We used Gitlab for version control as gitab provides more space which is required for a project created in Unity.

Google Drive - We used google drive to store our documentation.

3.2 Implementation Specifics

Here are detailed explanations of how the base classes specified in the previous section are implemented.

3.2.1 User Interface

Functioning of the user interface and display panels were done through C# scripts. Interaction panel contains sliders, buttons and descriptive text. The scripting reference is arranged in accordance with the classes that are accessible to scripts, each of which is detailed together with its methods, properties, and other usage-related details.

3.2.2 Visualization Of the Process

Visualization of the application was made using the in-built Unity animator and state machine. The state machine, which can be viewed as a flow-chart of animation clips and transitions or as a straightforward program written in a visual programming language within Unity, is utilized by the animator controller to control the various animation clips and the Transitions between them.

4 Conclusion

A Windows-based application for illustrating and educating about the Green Hydrogen Production Process and its usage in a bigger picture has been developed.

For the application development, Unity3D development tools were chosen because of their high-quality next-generation visual effects. The highly customizable rendering technology by the game engine and a variety of intuitive tools were used to create our current application.

The developed application is built to provide a video game-like interface, where children or interested candidates with non-engineering backgrounds could look and know about the process through visual representation. The application involves illustrations and an explanation of the major components involved in the process. The application also provides the user with real-time information such as power produced by the wind turbines and hydrogen production, based on the user input of wind speeds. Furthermore, there have been characters placed inside the application which explain to the user about different processes involved in green hydrogen production.

The end result is a Windows application that would help visualize and understand the major components involved in Green Hydrogen Production and usage on a macroscopic level.

5 Bibliography

HYDROGENICS. (2018). *Renewable Hydrogen Solutions*. Retrieved from cummins.com: https://www.hydrogenics.com/technology-resources/hydrogen-technology/electrolysis/

Petronilla Fragiacomo, M. G. (2020). Developing a mathematical tool for hydrogen production, compression, and storage. *International Journal of Hydrogen Energy, 45*(35), 17685-17701, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2020.04.269.