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SusFE

D4.1 Report on measured power and energy profiles for each subassembly and the summated global profile

Deliverable No.	D4.1	**Due Date**	30/September/2023
Description	Report on measured power and energy profiles for each subassembly and the summated global profile, resulting in a digital model that can estimate such profiles based on suitable inputs (measurement frequency, external interrupts, etc.)		
Type	Report	**Dissemination Level**	PU
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Abstract

D4.1 Report on measured power and energy profiles for each subassembly and the summated global profile describes the operation of an electronic platform developed by BeFC, having similar functionality to the electronics being developed as part of SusFE project. It also includes a power profile of said platform that can be used as a reference for the designs performed by other project partners.

Statement of originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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About this deliverable

D4.1 Report on measured power and energy profiles for each subassembly and the summated global profile is an internal deliverable. It aims at sharing the details of a demo electronic platform developed by BeFC for its internal use, which has components similar to the ones being designed as part of the SusFE project. This document will cover the design and functions of the platform as well as provide the power profile of the fuel cell powering the platform. The aim is to share the operation of the fuel cell in preparation for the custom electronics that are being developed by SusFE project partners.

Originally, this deliverable was meant to describe the findings of the measurements of the power needs of the aforementioned custom electronics. However, as the project is reaching the end of its first year, these electronic components are still under development, hence the measurement of their power requirements is not possible. The demo platform had been chosen for this report as an alternative.

Deliverable context

Table 1. Deliverable context

PROJECT ITEM IN THE DOA	RELATIONSHIP
Project Objectives	This deliverable does not directly contribute to the objectives of the project, but it demonstrates the capabilities of the BeFC's fuel cells to power conventional electronics.
Exploitable results	There is no specific contribution to any exploitable results.
Workplan	D4.1 is attributed to the tasks of WP4 Power management – bioenzymatic fuel cell.
Milestones	D4.1 is a key deliverable for demonstrating the power generation capabilities of the bioenzymatic fuel cells.
Deliverables	D4.1 describes an electronic platform with some of the functionality similar to the SusFE target electronic system, namely NFC and sensor data reading and storage, powered by a bioenzymatic fuel cell.
Risks	As a facilitator of the collaborative work within the project, D4.1 reduces project risks generally.

1 Electronic platform

The electronic platform described in this document has been developed by BeFC as a demo to show the feasibility of using the bioenzymatic fuel cell as a power source for conventional electronics. It is shown on Figure 1 below.

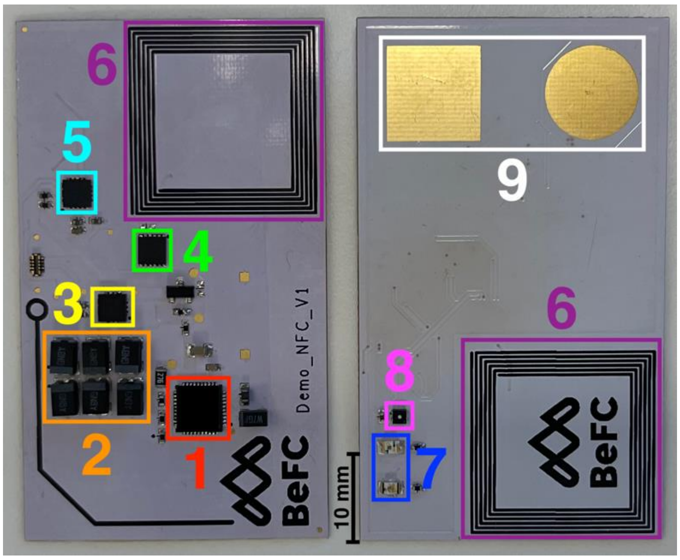

Figure 1. Photo of the electronic platform with a DC/DC converter (1), supercapacitors (2), transistor gate driver (3), NFC memory module (4), MCU (5), NFC antenna (6), LEDs (7), T/RH sensor (8), and landing pads for the fuel cell (9).

1.1 Power management

1.1.1 Power conversion

A single fuel cell produces approximately 1mW/cm^2 at 0.6V – 0.7V. Although the power is enough for some of low power Integrated Circuits (ICs), the voltage is below the typical minimum threshold of 1.8V. Therefore, the voltage has to be increased in order to meet the minimum requirements for powering the ICs.

There are two ways in which this can be achieved, namely connecting multiple fuel cells in series or using a step-up (boost) DC/DC converter. Series connection of the fuel cells is possible, but lossy due to the inherent contact resistance that would increase with each additional fuel cell in the series connection. This resistance will contribute to power loss, therefore this method, although possible, is not considered feasible.

Use of a DC/DC boost converter comes with its own challenges. For a DC/DC converter to operate, it requires an input voltage over a certain, model dependent, value. There are some DC/DC boost converters that can work with the input voltages as low as 0.3V, however this is only true after they "warm up". Before this, a higher input voltage, known as cold start voltage, is required. As the voltage generated by a single fuel cell is in the range of 0.6V – 0.7V, this again falls below the minimum cold start voltage of most conventional DC/DC boost converters. The DC/DC converter utilised in the electronic platform described in this document has been designed specifically for energy harvesting applications and as such its cold start voltage is below the single fuel cell potential.

Some operations of the electronic platform require more instantaneous power than the fuel cell can provide, hence storage capacitors have been added. They act as an energy buffer for when a high current burst is needed by the electronics, or when a long operation is taking place, such as writing a sensor reading into the memory for example. These capacitors are replenished from the fuel cell during the platform sleep cycle at a rate not exceeding that of a fuel cell.

1.1.2 Power saving strategy

All active (i.e., requiring power to operate) electronic components consume energy not only while operating, but also while they are idle. This is known as leakage current. However small, this leakage can add up if the component spends more time in the sleep cycle than it does in operation. For the electronic platform described here this is the case as the sensor reading time is in the order of tens of milliseconds, memory write operation is in the order of a few hundreds of milliseconds, while the sleep time is in the order of minutes. Hence the leakage current reduction will positively impact the lifetime of the platform.

The first strategy employed to combat the leakage current was to select the components with the lowest possible leakage. This has helped to reduce the leakage, but not to eliminate it.

Second strategy was to cut the power entirely to the parts of the platform that do not need power during the sleep cycle, such as the sensor, MCU and memory. This has been done with the use of a transistor gate driver with a built-in Real Time Clock (RTC), where the transistor is positioned in such way so as to cut the main power line to the MCU, memory and sensor. The leakage current of the RTC gate driver is far lower than any of the other components leading to the significant reduction of the power consumption during the sleep cycle.

1.2 Sensing

The electronic platform described in this document has the ability to measure temperature (T) and relative humidity (RH). This is done via a single off-the-shelf sensor combining both the temperature and the RH sensors in the same package. The sensor is positioned on the back side of the platform (Figure 1) to study the use of the platform as a skin temperature sensing patch.

1.3 NFC memory

The electronics platform described here uses a Near Field Communication (NFC) enabled memory module. This is a dual interface module, the data is written by the microcontroller (MCU) via a standard wired communication protocol (I^2C). It is also possible to write the data via the NFC interface through an external device, such as an NFC enabled mobile phone for example, for the MCU to read at the next wake-up in order to change the operation of the platform, for example changing the sleep cycle duration.

The NFC memory module does not require power from the fuel cell to communicate with the NFC reader or a smartphone. All required power is delivered via the NFC field generated by the reader. Hence the data stays recoverable even in the event of the fuel cell being depleted and unable to power the platform. The retention time is in the order of decades, thus data recovery remains possible for a long time after the use of the platform.

1.4 MCU

The MCU of the electronics platform has been chosen for its low operating power and the low number of passive components required for its operation, leading to a reduction of the Bill Of Materials (BOM). This is an ARM architecture microcontroller, it is responsible for communicating with the sensor, decoding and re-encoding its readings and writing them into the memory. It is also responsible for setting the sleep cycle duration either to a pre-programmed value or to a value written to the NFC memory via an external device.

1.5 Input/Output

The electronic platform is equipped with two light emitting diodes (LEDs) to serve as indicators. These LED colours are red and blue, for showing the exceeding of the temperature and humidity limits respectively. The LEDs will flash when a pre-defined threshold of temperature and/or humidity has been exceeded.

As the electronic platform is collecting the data at frequent intervals for the duration of its operation, this data is stored in the NFC memory module. The module can be accessed via a dedicated smartphone app, or via a dedicated reader.

2 Operation

This section describes the operation of the electronic platform and its dedicated smartphone app.

2.1 Electronic platform

Once the fuel cell is connected to the platform and activated, the DC/DC converter will start to extract the power from the fuel cell and using it to charge the capacitors until they reach a pre-defined voltage of 4V. These capacitors are used as a buffer to provide the high energy bursts during the wake-up cycle when all of the electronic components need to be powered. The charging of the capacitors can be seen on Figure 2.

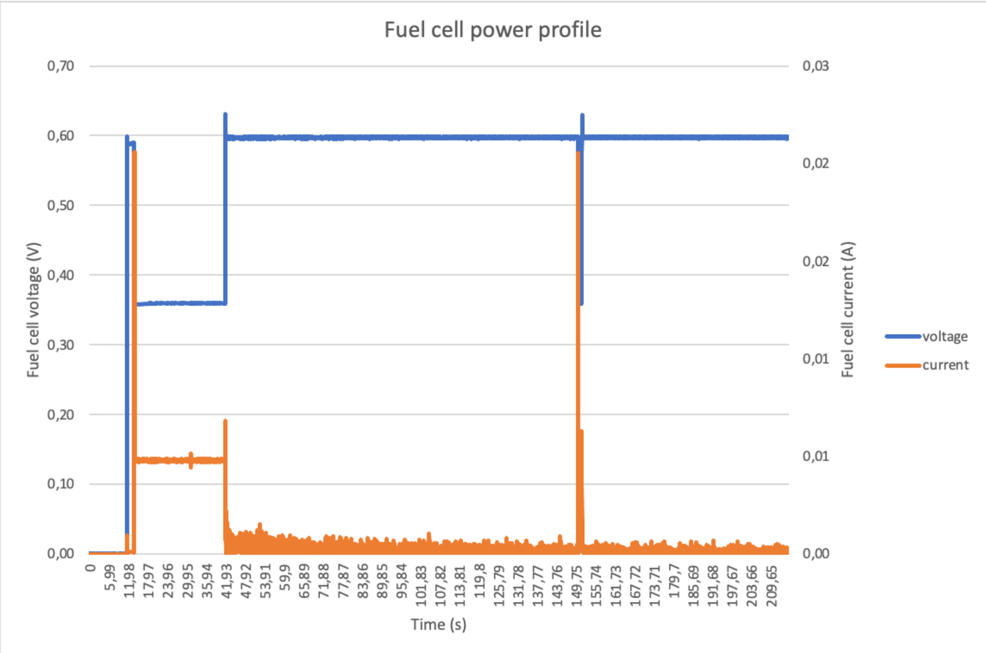

Figure 2. Fuel cell power profile showing startup and a single platform wakeup cycle.

Once the maximum capacitor voltage has been reached, the DC/DC converter will enable the main power line, thus powering the MCU. In turn, the MCU will check the memory module to work out if this is the first wake-up cycle, in which case it would set the parameters of other components, such as the transistor gate driver and the T/RH sensor. Once this is done the MCU will request the readings from the sensor and the value of the real time clock from the transistor gate driver and store these in the memory. Then, it will compare the values received from the sensor with the pre-defined threshold and if the values exceed this threshold, the MCU will power the corresponding LEDs.

At this stage the wake-up cycle is concluded, so the MCU will send a “done” signal to the gate driver, which in turn will close the transistor controlling the power line to the MCU, sensor, LEDs and memory in order to conserve power.

Depending on the configuration, the MCU can change the sleep cycle duration at the end of the wake-up cycle by sending an appropriate command to the transistor gate driver.

The RTC value can also be changed by writing the new value to the NFC memory via an external reader. This value will be uploaded to the RTC transistor gate driver by the MCU at the next wake-up cycle.

2.2 Smartphone app

In order to recover the data stored on the electronic platform a dedicated NFC reader or an NFC enabled smartphone with a dedicated app is required. For this platform the former was chosen as it makes the platform readily useable since most modern smartphones include the NFC capability.

When the app is launched and the platform is within the reach of the NFC field generated by the smartphone, the communication between the two will begin. The phone will read the data from the memory module, decode it and present to the user in human readable format, as well as graph the data to facilitate analysis. Figure 3 shows the screenshots of the app with both tabular and graphical data representations.

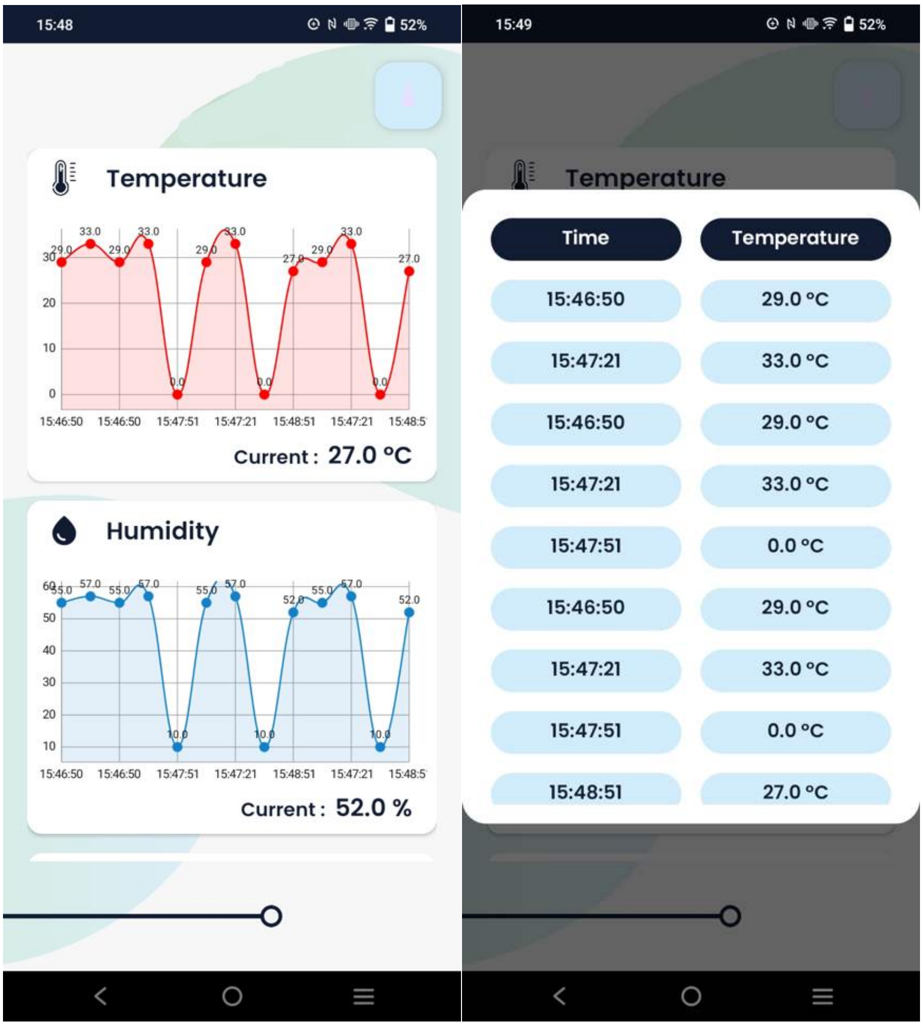

Figure 3. Data presentation in the smartphone app.

3 Conclusion

This report has presented the electronic platform developed by BeFC and powered by a bioenzymatic fuel cell. The platform has been shown to have the ability to use a T/RH external sensor together with an NFC memory to collect and store the measurement information. The energy required for all of the operations of the platform had come from the fuel cell, thus demonstrating the feasibility of using the fuel cell as a power source for conventional electronics.

In addition to this, a smartphone app had been developed for ease of data recovery from the platform. The app is using the built-in NFC module of modern smartphones to establish communications with the platform and interrogate the memory module. This operation does not require power from the fuel cell as the smartphone is powering the NFC memory module through the induced field.

The power profile of the fuel cell during platform's operation had been presented. It can be used as a reference as well as a guide to understanding the behaviour of the fuel cell under load. As the fuel cell acts differently to a conventional battery, the power profile will help with developing power management systems for the use in SusFE project.