AUTONOMOUS WASTE-TO-VALUE CONVERSION

PROJECT WORK – II (191EC89) REPORT

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BONAFIDE CERTIFICATE

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT

Biogas to electricity conversion is a sustainable and eco-friendly method of generating power by utilizing organic waste materials. Biogas primarily consists of methane (CH_4) and carbon dioxide (CO_2), produced through the anaerobic digestion of biodegradable materials such as animal manure, agricultural residues, food waste, and sewage sludge. This process involves microorganisms breaking down organic matter in an oxygen-free environment, resulting in the release of biogas. Once produced, biogas can be cleaned and upgraded to improve its methane content, which enhances its energy efficiency. The purified biogas is then used as a fuel to generate electricity through various technologies, the most common being gas engines or microturbines. In a combined heat and power (CHP) system, biogas can simultaneously produce electricity and useful thermal energy, increasing overall efficiency and reducing energy costs. The electricity generated from biogas can be used on-site for farms, industrial facilities, and households, or it can be fed into the electrical grid. This decentralized power generation model reduces dependence on fossil fuels and lowers greenhouse gas emissions. Additionally, the by-products of the digestion process, known as digestate, can be used as nutrient- rich organic fertilizer, supporting sustainable agricultural practices. The implementation of biogas-to-electricity systems supports waste management, energy security, and rural development. It transforms organic waste liabilities into valuable energy assets, promoting circular economy principles. With the increasing focus on renewable energy and carbon footprint reduction, biogas technology presents a promising solution for clean and reliable electricity generation.

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LIST OF ABBREVIATIONS

LED	LIGHT EMITTING DIODE
LCD	LIQUID CRYSTAL DISPLAY
PWM	PULSE WIDTH MODULATION
IR	INFRA RED
AC	ALTERNATING CURRENT
IDE	INTEGRATED DEVELOPMENT ENVIRONMENT
DC	DIRECT CURRENT
PLC	PROGRAMMABLE LOGIC CONTROLLER
USB	UNIVERSAL SERIAL BUS
AD	ANAEROBIC DIGESTION
DMM	DIGITAL MULTI METER
RMS	ROOT MEAN SQUARE

CHAPTER 1

INTRODUCTION

As the global demand for sustainable and renewable energy sources continues to rise, biogas has emerged as a promising solution to reduce dependence on fossil fuels and minimize environmental impacts. Biogas is a renewable energy source produced through the anaerobic digestion of organic materials such as agricultural waste, animal manure, food waste, and sewage sludge.

This biological process generates a mixture primarily composed of methane (CH_4) and carbon dioxide (CO_2), with methane being the combustible component responsible for energy production. By utilizing technologies such as gas engines, microturbines, or fuel cells, biogas can be harnessed to generate electrical power that can be used locally or fed into the grid.

This not only provides a clean energy alternative but also offers an effective waste management solution, turning pollutants into power. Moreover, the process generates useful byproducts such as heat, which can be captured for additional energy efficiency in combined heat and power (CHP) systems, and digestate, a nutrient-rich substance that can be used as a natural fertilizer. Implementing biogas-to-electricity systems contributes significantly to reducing greenhouse gas emissions, lowering energy costs, and supporting sustainable agricultural and industrial practices.

As technological advancements continue to improve the efficiency and scalability of biogas energy systems, they are becoming increasingly viable for both rural and urban communities, aligning with global efforts toward a more sustainable and circular economy.

CHAPTER 2

LITERTURE REVIEW

Marian Mendoza(2024) introduced a detailed analysis of biogas production from the oxidation lagoons of Siguatepeque, Honduras explores the potential of repurposing municipal wastewater treatment facilities into renewable energy sources through anaerobic digestion. Mendoza assesses the organic load and hydraulic retention times within the lagoons to determine their capacity to produce biogas, primarily composed of methane. She further evaluates the feasibility of converting the captured biogas into electricity using technologies such as gas engines or microturbines, with the aim of supplying power either to the local grid or for on-site energy needs. In addition to its technical analysis, the study underscores the environmental benefits of this approach, including reduced greenhouse gas emissions, improved waste management, and enhanced sanitation.

R. J. Orellana-Lafuente et al. (2024) introduced Distributed Biogas System from Wastewater Treatment Plants analysis of biogas utilization for electricity generation versus upgrading to biomethane, based on real operational data from a biogas plant in Italy. The plant, which processes the organic fraction of municipal solid waste, initially focused on electricity production through internal combustion engines and later transitioned to biomethane production for injection into the natural gas grid. The study evaluated the CO_2 emissions savings of both configurations, considering the Italian electricity mix and natural gas carbon intensities, including upstream emissions.

Meisam Mahdavi(2023) conducted a comprehensive analysis of renewable energy generation methods, focusing on photovoltaic (PV) systems, wind turbines, and biogas units utilizing chicken manure. The research aimed to evaluate the feasibility and performance of these technologies in rural areas, particularly in the Fez-Meknes region of Morocco. By considering factors such as water consumption of animals and the operation of anaerobic digesters, the study provided insights into the integration of these renewable energy sources. The findings highlighted the potential of hybrid systems combining biomass, solar, and wind energy to meet the electricity demands of rural communities effectively. This approach not only addresses energy access challenges but also promotes sustainable waste management practices by utilizing chicken manure for biogas production. The study's outcomes contribute to the broader understanding of renewable energy applications in rural settings and support the development of strategies for sustainable energy solutions.

Kaiyue Zhang etal(2024) conducted a comprehensive performance analysis and optimization of a small-scale biogas liquefaction system intended for integration with biogas power plants. The research focused on enhancing the efficiency and feasibility of liquefying biogas, particularly for applications in decentralized energy systems. By employing advanced simulation models, the study evaluated various parameters influencing the liquefaction process, such as energy consumption, system design, and operational conditions. The findings provided insights into optimizing the liquefaction system to achieve better energy efficiency and cost-effectiveness, thereby contributing to the broader adoption of biogas as a renewable energy source. This work underscores the potential of small-scale biogas liquefaction systems in supporting sustainable energy solutions, especially in regions where centralized energy infrastructure is limited.

Sunday A. Afolalu etal(2024) provide a comprehensive examination of biogas production via anaerobic digestion, emphasizing its role as a sustainable energy source. The study delves into the mechanisms of anaerobic digestion, where organic materials such as food waste and animal manure are broken down by microorganisms in oxygen-free environments to produce biogas—a mixture predominantly composed of methane and carbon dioxide. The authors highlight the environmental benefits of this process, including the reduction of greenhouse gas emissions and the mitigation of waste management challenges. Additionally, the paper discusses the potential of co-digestion strategies, such as combining kitchen waste (KW) and poultry manure (PM), to enhance biogas yield and process efficiency. By presenting a detailed analysis of the biochemical processes, feedstock characteristics, and operational parameters influencing biogas production, the study underscores the viability of anaerobic biodigestion as a clean, renewable energy solution with minimal environmental impact.

O.P. Odekunle etal(2023) conducted a feasibility analysis of a hybrid distributed energy system (DES) designed to supply power to the micro-grid at Ashesi University in Ghana. The proposed system integrates solar photovoltaic (PV) panels, biogas generation, and grid electricity to create a sustainable and reliable energy solution for the university campus. The research focused on evaluating the technical and economic viability of this hybrid approach, considering factors such as energy demand patterns, resource availability, and cost implications. The study concluded that implementing such a hybrid DES could enhance energy security, reduce reliance on the national grid, and promote the use of renewable energy sources within the university setting. This work contributes to the broader discourse on sustainable energy solutions for institutional applications in sub-Saharan Africa.

Renán Jorge Orellana-Lafuente etal(2024) evaluates the feasibility of implementing a distributed energy system that utilizes biogas produced from wastewater treatment plants (WWTPs). The study focuses on the techno-economic aspects of integrating biogas-based distributed generation (DG) systems within WWTPs, aiming to enhance energy efficiency and sustainability. By analyzing various operational scenarios, the research assesses the potential for energy recovery through anaerobic digestion processes, where organic matter in wastewater is broken down to produce biogas—a mixture primarily composed of methane and carbon dioxide. The authors explore the economic viability of such systems by considering factors like capital investment, operational costs, and potential revenue from energy generation.

H. G. Cho, H. C. Lee, J. S. Park, K. W. Kim, Y. H. Lee(2023) proposed Structural Optimization of Biogas-SOFC Systems for Sustainable Electricity Production that discusses the optimization of biogas-Solid Oxide Fuel Cell (SOFC) systems to produce electricity. It includes a design that uses steam reforming for hydrogen production, which is then utilized by fuel cells for power generation. It also integrates energy-saving features like CO_2 removal and anode/cathode gas recycling.

M. Iqbal, A. W. Khan, M. S. Asghar, H. A. Khan(2023) prposed automated Power Generation Using Biogas and Thermo-Electric Generators with AI Technology proposes an automated system for generating power from biogas using Thermo-Electric Generators (TEGs), enhanced by artificial intelligence (AI).The AI algorithms control the system to optimize power production, ensuring reliability and high efficiency.

Yoo et al. (2024),conducted a comprehensive investigation into enhancing the efficiency and performance of anaerobic digestion (AD) systems through temperature-phased digestion and co-digestion strategies. The researchers focused on optimizing the digestion environment by integrating mesophilic and thermophilic phases in a sequential setup, which improved the breakdown of complex organic compounds and enhanced microbial activity. This temperature-phased approach significantly increased the hydrolysis rate, leading to faster and more complete degradation of substrates. Furthermore, the study examined the synergistic benefits of co-digestion, particularly the combination of food waste with agricultural residues, such as crop silage and manure. Yoo et al. found that co-digestion not only provided a more balanced carbon-to-nitrogen (C/N) ratio but also improved the availability of trace elements and buffering capacity in the digester. As a result, the methane yield was boosted by up to 30% compared to mono-digestion scenarios. The findings highlight how tailored feedstock blends and thermally optimized processes can substantially enhance biogas production, making AD systems more economically viable and environmentally sustainable, especially for decentralized waste management and renewable energy generation.

Kumari et al. (2023)conducted a pivotal review on the role of microbial consortia engineering in enhancing the efficiency and resilience of anaerobic digestion (AD) processes, particularly under diverse and fluctuating substrate conditions. Their research emphasized that traditional AD systems often face challenges in maintaining stable methane production when fed with mixed or inconsistent organic wastes—such as combinations of food waste, agricultural residues, and manure. To address this, the study explored the application of engineered microbiomes—carefully selected and cultivated microbial communities designed to perform specific metabolic functions within the digester. By introducing synthetic consortia or selectively enriching native microbial populations, the degradation of complex polymers like lignocellulose and lipids was significantly accelerated. Kumari et al. highlighted how these advanced microbiomes improved process stability, even under conditions of substrate variability, high organic loading rates, and ammonia inhibition. Additionally, the review noted that genome-guided selection and metagenomic analysis allow for precise tailoring of microbial communities to enhance methane yields and reduce lag phases. This approach represents a shift toward precision microbiology in biogas systems, enabling more predictable and efficient performance, particularly in commercial and high-throughput AD facilities.

Krich et al. (2023) presented an updated comparative study that evaluated the performance of biogas-based gas engines and microturbines in various scales of electricity generation. Their findings revealed that gas engines remain the preferred technology for large-scale biogas plants due to their relatively higher electrical efficiency, typically ranging between 35% and 42%. These engines are well-suited for continuous operation, have mature technology support, and can be easily integrated with combined heat and power (CHP) systems to further enhance overall energy output. On the other hand, microturbines, while offering slightly lower electrical efficiency (generally between 25–30%), stand out in small-scale and decentralized applications due to their compact design, lower maintenance needs, quieter operation, and better tolerance to biogas contaminants. Krich et al. emphasized that microturbines are particularly advantageous in urban or remote settings where space, noise, and emissions are critical concerns. Their modularity also allows easier scalability in community-level or distributed energy systems.

Samanta et al. (2024) conducted an in-depth review of the application of fuel cells, particularly Solid Oxide Fuel Cells (SOFCs), in biogas-to-electricity conversion systems. SOFCs operate at high temperatures (typically around 800°C), which allows them to internally reform biogas—primarily methane—into hydrogen, eliminating the need for external reforming equipment. This results in a highly efficient direct conversion of chemical energy into electricity, with reported electrical efficiencies ranging between 50–60%, significantly higher than traditional internal combustion engines. Furthermore, the high operating temperature enables the recovery of waste heat, making SOFCs suitable for integration into combined heat and power (CHP) systems, which can push overall energy efficiency even higher. The review emphasized that SOFCs produce very low emissions, including negligible levels of nitrogen oxides (NOx) and particulate matter, making them an environmentally friendly alternative.

CHAPTER 3

DESIGN METHODOLOGY

3.1 INTRODUCTION

Biogas, produced through the anaerobic digestion of organic waste, is a clean, renewable energy source primarily composed of methane and carbon dioxide. It can be used to generate electricity via gas engines, microturbines, or fuel cells, offering both sustainable energy and effective waste management. The process also produces heat and nutrient-rich digestate, enhancing energy efficiency and agricultural productivity. As technology advances, biogas systems are becoming more efficient and scalable, making them a viable solution for reducing emissions, lowering energy costs, and supporting a circular economy in both rural and urban areas.

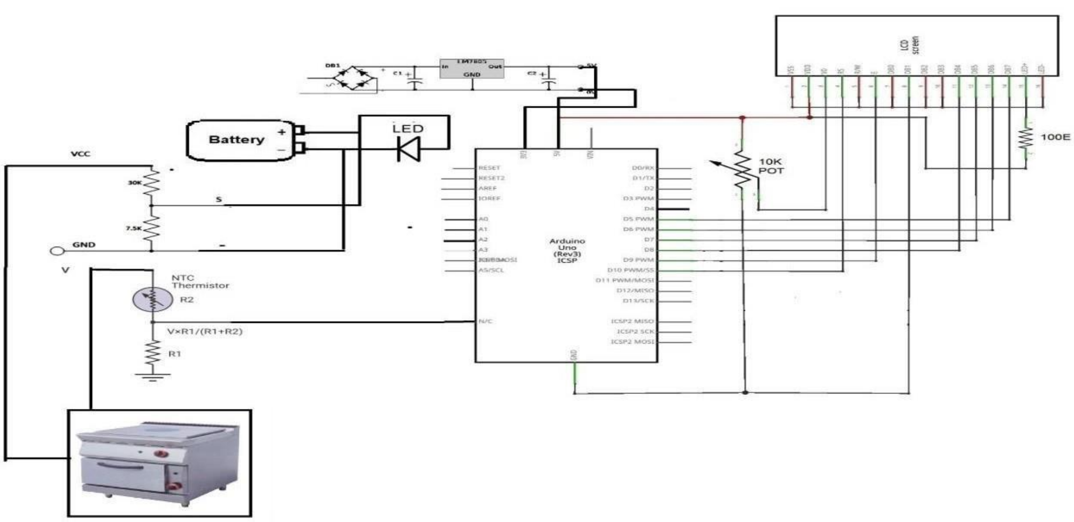


Fig. 3.1 Circuit Diagram

Biogas is a type of renewable energy that is produced through the anaerobic digestion of organic matter by microorganisms in the absence of oxygen. This organic matter can include agricultural waste, food waste, animal manure, sewage, and plant material.

1. **Biogas Production Process**

   - **Anaerobic Digestion:**

   Organic waste is placed in a biogas digester – a sealed, oxygen-free tank. Inside, bacteria break down the material, releasing a mixture of gases. The main components of biogas are:

     - **Methane (CH_4)** – 50–70%
     - **Carbon Dioxide (CO_2)** – 30–40%
     - Small amounts of hydrogen sulfide (H_2S), moisture, and other gases

   - **Types of Digesters:**
     - **Batch Digesters:** Loaded once and left to digest for a period.
     - **Continuous Digesters:** Fed with waste regularly and produce biogas continuously.

The process not only produces biogas but also creates digestate, a nutrient-rich byproduct that can be used as fertilizer.

2. **Biogas Purification**

   Before using biogas to generate electricity, it may be cleaned and upgraded:

   - **Moisture Removal:** Using coolers and condensers
   - **H_2S Removal:** Activated carbon or iron oxide filters
   - **CO_2 Removal (Optional for high-grade fuel)**

3. **Electricity Generation Methods**

   There are several ways to convert biogas into electricity:

a. Internal Combustion Engines

- The most common method.
- Biogas is burned in a gas engine, which drives a generator to produce electricity.
- Can be combined with heat recovery systems (CHP – Combined Heat and Power) for higher efficiency.

b. Gas Turbines

- Suitable for larger plants.
- Biogas is combusted to produce high-pressure gas that spins turbine blades connected to a generator.

c. Fuel Cells

- A more advanced and cleaner technology.
- Biogas is reformed to hydrogen, which powers a fuel cell to generate electricity with very low emissions.

d. Applications and Benefits

- **Off-grid electricity for farms, rural areas, and households**
- **Grid-connected electricity generation**
- **Environmental benefits**: Reduces greenhouse gas emissions, manages organic waste, and provides clean energy.

3.2 COMPONENT DESCRIPTION

3.2.1 ARDUINO UNO BOARD:

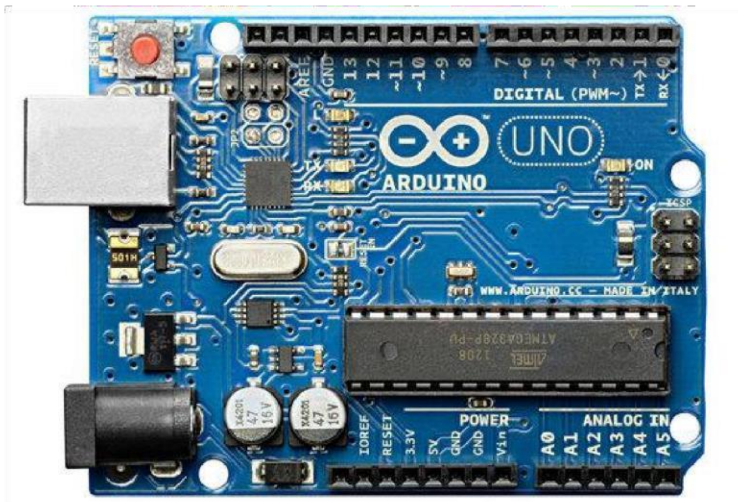


Fig. 3.2 Arduino UNO Board

The Fig. 3.2shows arduino uno microcontroller board. The Arduino Uno is a popular open-source microcontroller board, acts as a flexible platform for electronics prototyping and various projects. It relies on the ATmega328P microcontroller, offering a harmonious blend of performance and features suitable for a diverse array of applications. The Arduino Uno board offers remarkable versatility, empowering hardware developers to effortlessly embark on digital electronic projects, even with limited coding proficiency. It proves invaluable to enthusiasts and professionals alike, whether their interests lie in electronics or robotics.

The Arduino Uno integrates both analog and digital ports, seamlessly compatible with various external components like sensors, switches, push-buttons, and LED lights, eliminating the need for extra circuitry. Users can conveniently program the device either by crafting custom code on a computer via USB connection or by leveraging preloaded examples, simplifying programming even for those with minimal prior knowledge. Moreover, a distinct advantage of this platform lies in its extensive array of third-party modules, enabling users to expand their project capabilities far beyond the standard offerings. These modules span a diverse range, from wireless communication protocols such as Bluetooth Low Energy to sophisticated image processing systems like OpenCV.

Each module can seamlessly integrate into the user's design through standard interface pins, offering limitless potential for project expansion. The popularity of the Arduino Uno for initiating new development cycles is evident, primarily because of its accessibility and user-friendly nature, which simplifies the creation of intricate circuits. This accessibility ensures that individuals of varying technical backgrounds have equal opportunities to delve into embedded development.

3.2.1.1 ARDUINO UNO MICROCONTROLLER PIN CONFIGURATION:

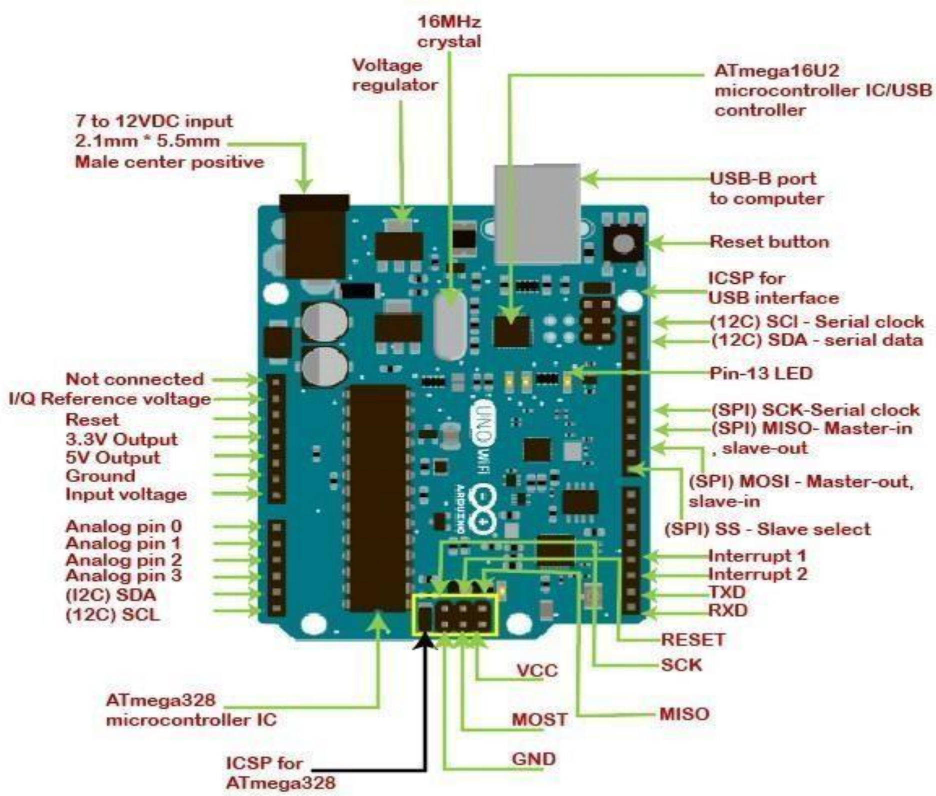


Fig. 3.3 Arduino Uno Microcontroller Pin Configuration

The Fig.3.3 shows arduino uno pin configuration. The Arduino Uno pin diagram visually depicts the arrangement and functions of the pins found on the board, facilitating a clear understanding of its operation. Below is a breakdown of the pins present on the Arduino Uno.

Digital Pins

There are fourteen digital input/output pins on the Arduino Uno, numbered 0 through 13. These pins perform a variety of tasks, including controlling motors, LED control, and measurements from sensors.

Digital Pin 0 (RX) - Consider this pin as the recipient of messages. It functions similar to the ears of your Arduino, attentively awaiting data from external devices or even your computer. This capability proves invaluable for gathering information from the external environment.

Digital Pin 1 (TX) - This pin takes on the role of the communicator. It acts akin to your Arduino mouth, transmitting messages to other devices or your computer. It proves handy when you desire your Arduino to disseminate information to the external world.

Digital Pins 2-13 - These pins are highly adaptable, serving dual purposes of control and sensing. Picture them as switches capable of toggling between on (HIGH) and off (LOW) states. They're instrumental in making LEDs blink, regulating motors, and even detecting signals from buttons or sensors.

Digital Pin 13 (LED) - This particular pin holds significance as it comes preconnected to a small built-in LED on the Arduino board. It functions akin to a miniature testing companion. It's handy for verifying if your Arduino is operating as expected and performing its tasks correctly.

PWM (Pulse Width Modulation) - Certain pins, typically 3, 5, 6, 9, 10, and 11, possess a neat capability. They can rapidly alternate between bright and dim states, resembling pseudo-analog behavior. This feature proves advantageous when you aim to regulate actions such as smoothly fading a light in and out.

Interrupts - Consider these pins as the "Hey, pay attention!" team. They gently nudge your Arduino whenever something significant occurs, like a sensor change or a button press. It's akin to having a friend who alerts you when something intriguing is happening. Understanding these digital pins opens up a plethora of creative possibilities. You can empower your Arduino to listen, communicate, blink, and react to its surroundings in countless imaginative ways!

Analog Pins

The analog pins on the Arduino Uno play a crucial role in interfacing with analog sensors and signals. Unlike digital pins that can only handle high (1) or low (0) states, analog pins can detect a continuous range of voltage levels. This feature proves invaluable when working with sensors providing analog output, such as light sensors, temperature sensors, potentiometers, and more. The Arduino Uno provides a sum of 6 analog input pins, designated from A0 to A5. Each of these pins is capable of measuring an analog voltage within the range of 0 to 5 volts. These analog pins boast a resolution of 10 bits, meaning they can accurately represent analog voltage levels using 2^10 (1024) discrete steps or levels.

Analog Pin A0 - This pin is capable of converting analog voltage into a digital value. With a resolution of 10 bits, it can discern 1024 distinct voltage levels ranging from 0 to 5 volts.

Analog Pin A1 - Like A0, this pin also possesses a 10-bit resolution, enabling it to interpret analog signals in a similar fashion.

Analog Pin A2 - Similar to A0 and A1, A2 has a resolution of 10 bits and can read analog signals.

Analog Pin A3 - Operating similarly to its counterparts, this pin also features a 10bit resolution for reading analog voltages.

Analog Pin A4 - Once more, this pin serves an identical function to the others, facilitating the reading of analog voltages with a 10-bit resolution.

Analog Pin A5 - Like the other analog pins, A5 is capable of reading analog signals with a resolution of 10 bits.

Power Pins

The Arduino Uno features multiple power pins designed for supplying power to the board and external devices.

5V Pin - This pin supplies a stable 5V DC output, suitable for powering external devices that necessitate 5V DC.

3.3 V Pin - This pin offers a regulated 3.3V DC output, ideal for powering external devices requiring 3.3V DC.

GND Pins - These pins serve as ground connections for the board, enabling the completion of circuits and offering a reference voltage.

VIN Pin - This pin, which accepts a voltage range of 7V to 12V DC, is used for charging the circuit board via a separate power source.

Other Pins

The Arduino Uno features various additional pins allocated for specific purposes.

Reset Pin - This pin serves as the reset mechanism for the board. Resetting occurs when the pin is set to LOW.

ICSP Header - This header facilitates programming of the board through an external programmer. The USB connection is employed for programming the board and establishing communication with other devices.

3.2.2 VOLTAGE SENSOR:

Fig. 3.4 Voltage Sensor

The Fig. 3.4 shows Voltage Sensor. In renewable energy systems such as biogas-based power generation, the accurate monitoring and control of electrical parameters are vital for efficient and safe operation. Among these parameters, voltage is one of the most critical. Voltage sensors play an essential role in biogas-to-electricity systems by measuring the electrical potential difference at various points of the system, ensuring stable power output and protecting both the generator and connected loads from fluctuations or faults.

Biogas is typically used to fuel internal combustion engines or gas turbines that drive electrical generators. These generators produce alternating current (AC) or direct current (DC) electricity, depending on the system design. Voltage sensors are integrated into this process to continuously measure and monitor the output voltage of the generator, helping regulate the power supply and ensure the system operates within its specified voltage range.

Working Principle of Voltage Sensors

Voltage sensors operate by comparing the measured voltage to a reference voltage. There are two primary types of voltage sensors used in biogas energy systems:

1. **Resistive Voltage Divider Sensors**: These are simple and cost-effective. They use two resistors in series to step down the high voltage to a measurable level, which is then read by a microcontroller or data acquisition system.
2. **Opto-Isolated Voltage Sensors**: These provide electrical isolation between the high-voltage power line and the monitoring/control system. This type of sensor is safer and more robust for high-voltage applications.

In modern systems, voltage sensors are often integrated with microcontrollers or PLCs (Programmable Logic Controllers) to enable real-time monitoring, data logging, and automated control of voltage regulation devices such as AVR (Automatic Voltage Regulators) or load control systems.

Role in Biogas Power Systems

Voltage sensors are used in several key areas of a biogas-to-electricity setup:

- **Generator Output Monitoring**: Ensures the voltage produced by the generator remains stable and within acceptable limits (e.g., 220V for single-phase or 400V for three-phase systems).
- **Battery Charging Control (in hybrid systems)**: In setups that include battery storage, voltage sensors help maintain proper charging voltages and prevent overcharging or deep discharge.
- **Grid Synchronization**: For grid-tied biogas systems, voltage sensors help ensure that the voltage phase and magnitude of the generator match those of the grid before synchronization.
- **Fault Detection and Protection**: If the voltage goes beyond preset thresholds, sensors trigger protective mechanisms like circuit breakers, shutdown signals,

or alarms.

Specifications and Features

A typical voltage sensor module used in biogas power systems may include the following specifications:

- **Input Voltage Range**: 0–250V AC or up to 600V for industrial setups
- **Output Signal**: Analog (0–5V) or digital (e.g., via I2C, SPI, or UART)
- **Accuracy**: ±1% or better
- **Response Time**: Less than 100 ms for real-time control
- **Isolation Voltage**: 2kV or higher for safety
- **Mounting**: DIN rail or panel mount
- **Temperature Range**: –20°C to +70°C

Some advanced sensors also include features like overvoltage and undervoltage detection, waveform monitoring, and wireless communication.

3.2.3 TEMPERATURE SENSOR:

Fig. 3.5 Temperature Sensor

The Fig. 3.5 shows the Temperature Sensor. Temperature sensors play a critical role in biogas-to-electricity conversion systems. These systems rely on the anaerobic digestion of organic matter to produce biogas, primarily composed of methane (CH_4) and carbon dioxide (CO_2). The performance and efficiency of the anaerobic digestion process are highly temperature-dependent. Hence, accurate temperature monitoring and control are essential to ensure optimal biogas production and reliable electricity generation.

Importance of Temperature Monitoring

The anaerobic digestion process occurs in several stages (hydrolysis, acidogenesis, acetogenesis, and methanogenesis), each involving different microbial communities that function effectively within specific temperature ranges. There are two main digestion temperature ranges:

- Mesophilic range: 30°C to 40°C
- Thermophilic range: 50°C to 60°C

Maintaining the digester within these ranges ensures microbial activity is at its peak, which leads to higher biogas yields. A deviation from the optimum temperature can result in reduced gas production, system instability, and even complete process failure.

Sensor Function and Placement

Temperature sensors are embedded at various points in the biogas plant, such as:

- Inside the anaerobic digester to monitor digestion temperature
- In the gas piping system, where the temperature affects gas volume and pressure
- Near the generator engine, as gas combustion temperature affects engine performance

These sensors help maintain a stable environment by feeding real-time data to the control system, which can then regulate heating elements, agitators, or cooling systems accordingly.

Types of Temperature Sensors Used

Depending on the design and requirements of the biogas system, different types of temperature sensors may be employed:

a) Thermocouples

Thermocouples are robust, inexpensive, and suitable for a wide temperature range. They are often used in biogas systems for their durability and quick response times.

b) Resistance Temperature Detectors (RTDs)

RTDs provide higher accuracy and stability than thermocouples, making them ideal for precise monitoring in the digester.

c) Thermistors

These are highly sensitive to small changes in temperature and are best used for narrow temperature ranges. Thermistors are cost-effective and useful in small-scale biogas plants.

d) Infrared (IR) Sensors

Used primarily for non-contact temperature measurement, IR sensors can be employed in locations where direct sensor placement is not feasible.

Integration with Control Systems

Temperature sensors are connected to the central control unit of the biogas-to-electricity system. The collected data is used for:

- Automated temperature control (e.g., turning heating elements on/off)
- Safety alerts in case of over-temperature conditions
- Data logging for performance monitoring and system diagnostics

In advanced systems, sensor data is also transmitted via wireless communication to remote monitoring stations, allowing for real-time diagnostics and performance optimization.

Challenges and Considerations

When choosing a temperature sensor for a biogas system, several factors must be considered:

- Corrosion resistance, especially due to the presence of hydrogen sulfide (H_2S) in biogas
- Sensor housing material to ensure longevity in harsh conditions
- Calibration and maintenance to ensure long-term accuracy
- Response time, especially for sensors used near engines or rapid-process areas.

- Proper installation and regular maintenance of temperature sensors are essential to prevent drift or sensor failure, which can compromise the entire biogas- to-electricity process.

3.2.4 LCD:

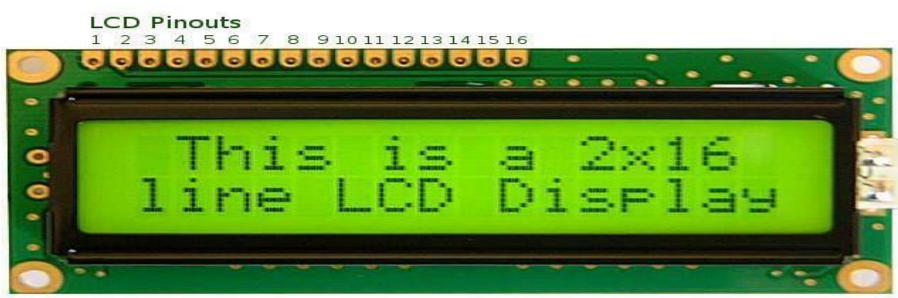


Fig. 3.6 LCD Display

A 16x2 LCD means it can display 16 characters per line and there are 2 such lines. In this LCD each character is displayed in 5x7 pixel matrix. This LCD has two registers, namely, Command and Data.

The command register stores the command instructions given to the LCD. A command is an instruction given to LCD to do a predefined task like initializing it, clearing its screen, setting the cursor position, controlling display etc. The data register stores the data to be displayed on the LCD. The data is the ASCII value of the character to be displayed on the LCD.

A liquid crystal display (LCD) is a thin, flat electronic visual display that uses the light modulating properties of liquid crystals (LCs). LCs do not emit light directly.

They are used in a wide range of applications including: computer monitors, television, instrument panels, aircraft cockpit displays, signal, etc. LCDs have displaced cathode ray tube (CRT) displays in most applications. They are usually more compact, lightweight, portable, less expensive, more reliable, and easier on the eyes.

PIN DESCRIPTION:

Most LCDs with 1 controller has 14 Pins and LCDs with 2 controller has 16 Pins (two pins are extra in both for back-light LED connections).

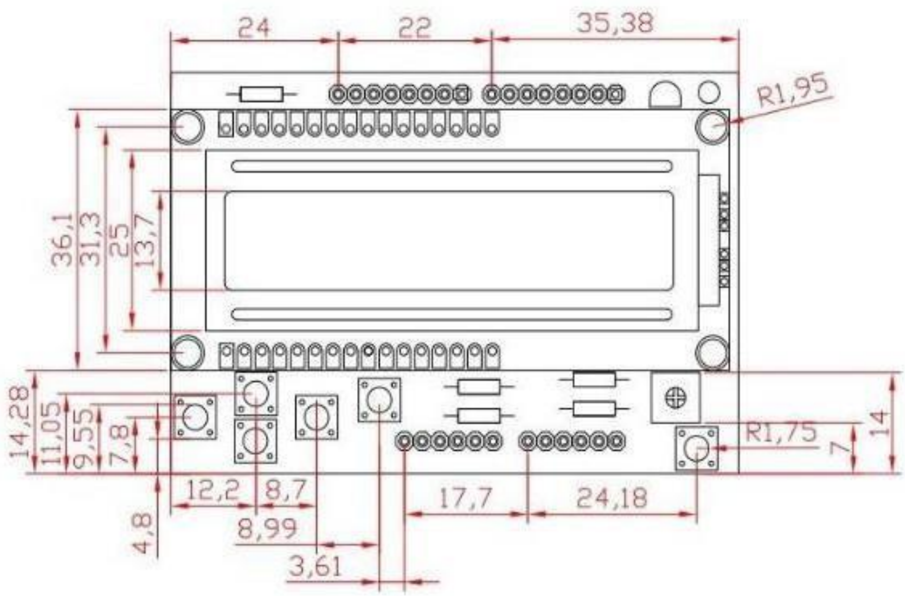


Figure Pin description

Functions of the LiquidCrystal and LiquidCrystal_I2C library

The LiquidCrystal library has 20 build in functions which are very handy when you want to work with the LCD display. In the following part of this article we go over all functions with a description as well as an example sketch and a short video that you can see what the function is doing.

Sr.No.	Hex Code	Command to LCD instruction Register
1	01	Clear display screen
2	02	Return home
3	04	Decrement cursor (shift cursor to left)
4	06	Increment cursor (shift cursor to right)
5	05	Shift display right
6	07	Shift display left
7	08	Display off, cursor off
8	0A	Display off, cursor on

Features:

- 16x2 LCD using HD44780-compatible display module (black characters on green background).
- 5 buttons on one analog input (A0).
- LCD backlight with current limiting, brightness and on/off controllable by a adjustable potentiometer.
- Recessed LCD, panel mount screw holes and button layout suitable for panel or cabinet mounting if desired.
- Reset button.
- Power supply smoothing capacitor.

BATTERY

LEAD ACID BATTERY

Overview The most common type of battery used on UPS systems and for backup of telecommunications systems. VRLA batteries are designed to be maintenance free and the hydrogen that is emitted is recombined internally so that the electrolyte does not need replacing over the life of the battery, a valve is installed to release any excess pressure that may build up if the battery were failing.

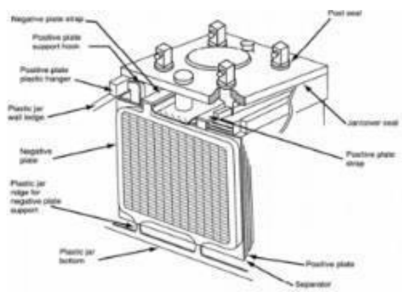


Plate thickness in this type of cell is determined by the application it is used in; long discharge durations require a thicker plate than high power rapid discharges which require thin plates.

Factors affecting battery life:

The VRLA battery is a sacrificial design, destined to eventually wear out even in ideal conditions, when abused; it will fail even sooner due to the following causes:
-Expansion and corrosion of the positive grid structure due to oxidation of the grid and plate materials. This degradation mechanism is unavoidable and is the most common natural failure mode for lead-acid batteries maintained on a float charge.

Loss of active material from the positive plate.

Loss of capacity due to physical changes in the active material of the positive plate.

Design life: VRLA batteries are typically available with a design life ranging from 3 to 10 years. Longer life batteries generally cost more due to increased plate thickness or more costly materials.

Temperature: Elevated temperatures reduce battery life. An increase of 8.3°C (15°F) can reduce lead-acid battery life by 50% or more.

Cycle service: Discharge cycles reduce life. Lead calcium batteries can be rated for as few as 50 deep discharge cycles. Many lifetime calculations for UPS systems are based on 1 to 2 Deep discharges per year. (Deep discharge is anything greater than 25% capacity)

Overcharging: Excessively high float voltages cause a higher positive plate corrosion rate. Overcharging also causes excessive gassing. Recharging after a discharge must be controlled to 10% of the discharge current to prevent damage to the cells. - Undercharging. A low float voltage reduces capacity because of self-discharge. Undercharging can also result in sulfation, which can damage the plates.

DC ripple current: Excessive DC ripple current might contribute to battery aging. VRLA batteries are considered to be extremely susceptible to ripple current since it can lead to cell heating and will accelerate the degradation of cells which are at risk from thermal runaway.

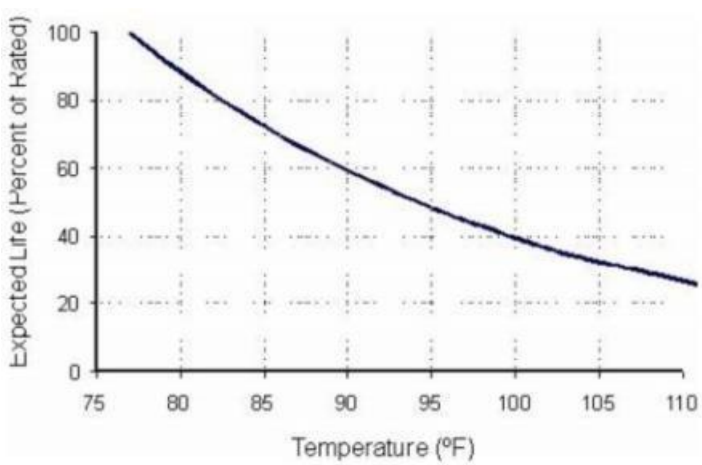
End of Life

If properly designed, built, and maintained, a battery can provide many years of reliable service. A new battery might not initially provide 100% capacity. The capacity typically improves over the first few years of service, reaches a peak, and declines until the battery reaches its end of life. A reduction to 80% of the rated capacity is usually defined as the end of life for a lead-acid battery. Below 80%, the rate of battery deterioration accelerates, and it is more prone to sudden failure resulting from a mechanical shock (such as a seismic event) or a high discharge rate. Note that even under ideal conditions, a battery is expected to eventually wear out.

Battery Failure Modes in Detail

Temperature Effects: Anticipated battery life is specified by the manufacturer for batteries installed in an environment at or near the reference temperature of 25°C (77°F). Above this temperature, battery life is reduced. The chief aging mechanism is accelerated corrosion of the positive plates, grid structure, and strap, which increases exponentially as a function of temperature.

Rule of Thumb: A general rule of thumb for a vented lead-acid battery is that the battery life is halved for every 15°F (8.3°C) above 77°F (25°C). Thus, a battery rated for 5 years of operation under ideal conditions at 77°F (25°C) might only last 2.5 years at 95°F (35°C)



Overcharging: Occasional charging at higher voltages, such as an equalizing charge, can benefit the battery by removing plate sulfation and refreshing the plates.

However, habitual overcharging damages the plates. The chart below highlights how charging at the wrong float voltage can drastically increase corrosion.

Undercharging: Batteries lose capacity because of self-discharge if they are consistently undercharged. An undercharge condition is indicated by a low specific gravity, low cell voltage, or lighter color on the plates. An undercharged battery might not be at full capacity and can become permanently damaged from sulfation. Chronic undercharging results in a harmful buildup of lead sulfate on the plates, called sulfation. Lead sulfate formed as a result of undercharging is inherently different in structure from lead sulfate formed during normal cell discharge. The lead sulfate formed during normal discharge has a very fine crystalline structure that is easily broken down by charging current. The lead sulfate crystals formed as a result of undercharging continue to grow and eventually reach a size that cannot be easily broken down by charge current. Additionally, the lead sulfate crystals physically occupy more space than the original active material. An excessive buildup of lead sulfate can make the plates warp or buckle.

3.2.5 INFRA RED SENSOR:

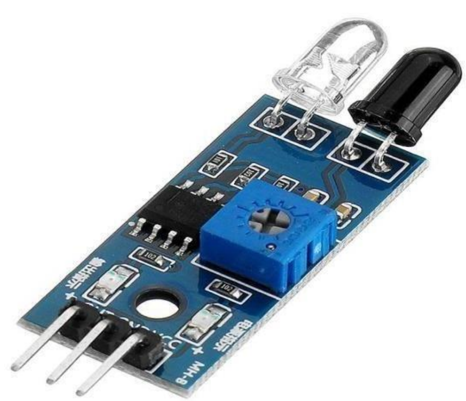


Fig. 3. 7 Infra Red Sensor

The Fig. 3.8 shows the Infra Red Sensor. An infrared (IR) sensor is crafted to identify and gauge infrared radiation within its ambient surroundings. Infrared radiation consists of electromagnetic waves with wavelengths longer than those of visible light, rendering it imperceptible to the human eye. The functionality of IR sensors is grounded in the principle that objects emit diverse amounts of infrared radiation contingent upon their temperature. Comprising an IR transmitter emitting infrared light and an IR receiver detecting the emitted radiation, these sensors are equipped to perceive objects within their field of view. When an object is present, the IR radiation it emits is captured by the sensor's receiver.

Subsequently, the sensor transforms this received signal into an electrical voltage, enabling it to discern the presence, absence, or proximity of objects. IR sensors are utilized across various domains, encompassing security systems, automation, communication devices, and medical equipment. Their common applications include tasks such as motion detection, object recognition, and temperature measurement. The widespread use of IR sensors is attributed to their reliability, precision, and adaptability to different lighting conditions.

3.3 SOFTWARE TOOL

3.3.1 ARDUINO IDE SOFTWARE:

Fig. 3.8 Arduino Ide Software

For people who utilize Arduino boards, the Arduino Integrated Development Environment (IDE) is a software platform that makes project development and programming easier. Arduino, a freely available electronics platform, integrates approachable hardware and software, catering to the needs of hobbyists, students, and professionals in the creation of interactive projects.

There are several operating systems that support the Arduino IDE, including Windows, macOS, and Linux. Customers have the option to get it straight from the official Arduino website and install it. (https://www.arduino.cc/en/software).

The IDE features a simple and user-friendly interface, comprising a text editor for code composition, a toolbar housing common functions, and menus providing access to various settings and options.

Within the code editor, users compose and edit their Arduino sketches (programs). It supports the C/C++ programming language and incorporates syntax highlighting, enhancing the ease of understanding and navigating the code. As open-source software, the Arduino IDE permits users to examine, modify, and actively contribute to its development. This openness encourages ongoing enhancements and customization to meet the evolving needs of users.

BLOCK DIAGRAM:

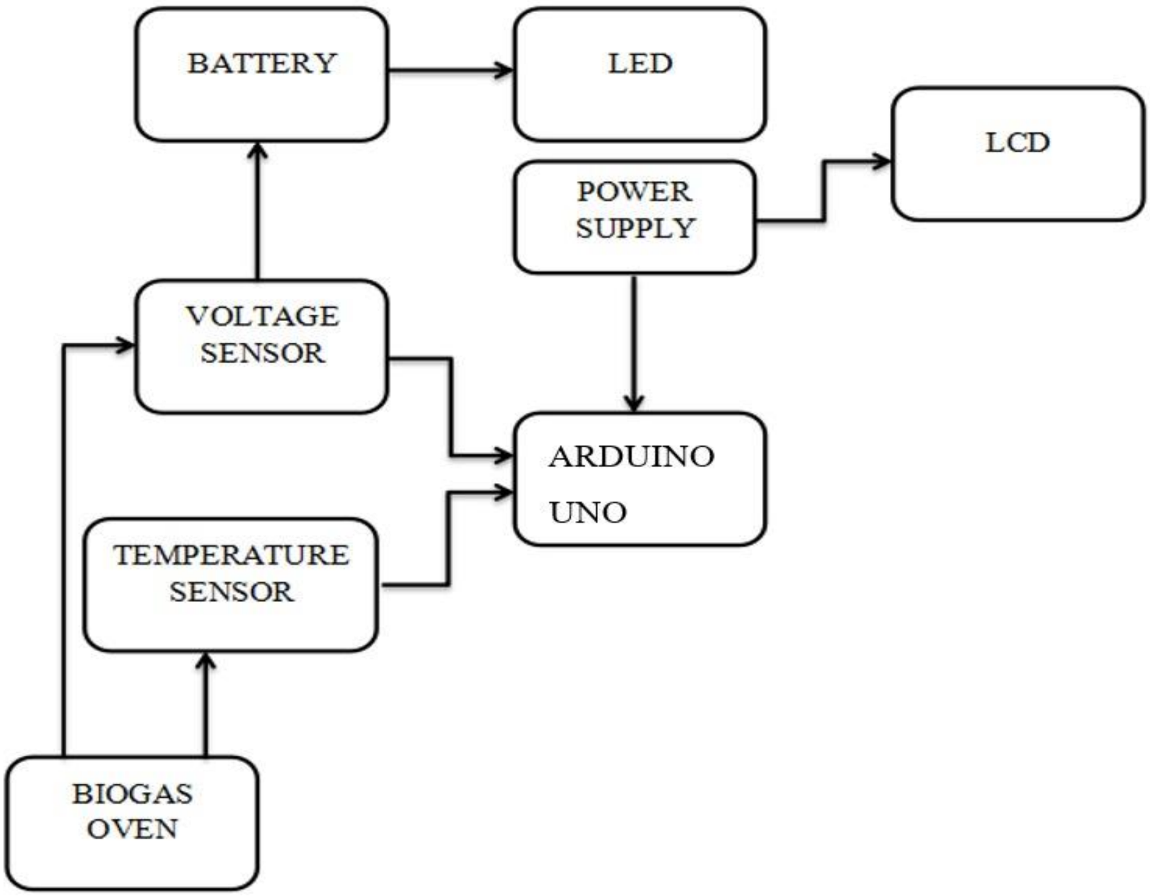
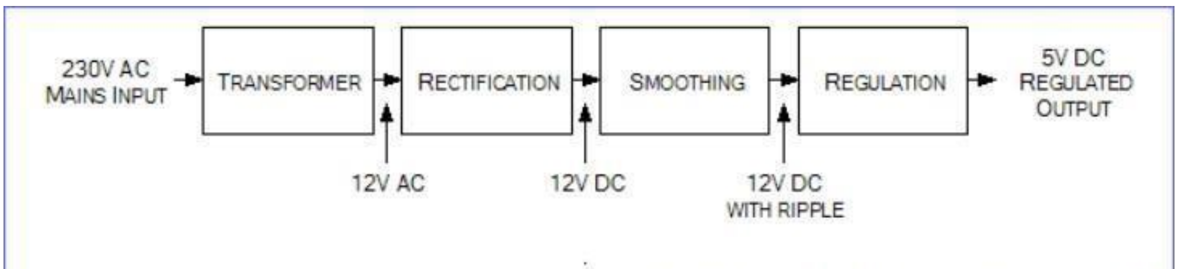


Fig. 3.9 Block Diagram

3.3.2 BLOCK DIAGRAM DESCRIPTION:

POWER SUPPLY

The block diagram of a power supply system which converts a 230V AC mains supply (230V is the UK mains voltage) into a regulated 5V DC supply.There are many types of power supply .which are designed to convert high voltage AC mains electricity to suitable low voltage supply for electronic circuits and other devices .A power supply can be broken in to a series of blocks each of which performs a particular function.



Block diagram of a power supply system

Blocks are described in more detail below:

Transformer – steps down high voltage AC mains to low voltage AC

Rectifier- converts AC to DC but the DC output is varying

Smoothing- smoothes the DC from varying greatly to a small ripple

Regulator- eliminates ripple by setting DC output to a fixed voltage

TRANSFORMER

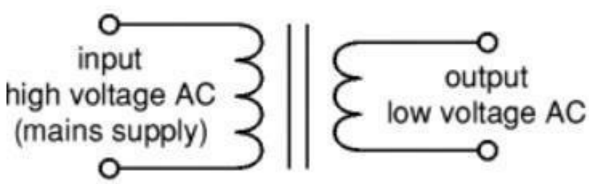
Transformers convert AC electricity from one voltage to another with little loss of power. Transformers work only with AC and this is one of the reasons why mains electricity is AC.

Step-up transformers increase voltage, step-down transformers reduce voltage. Most power supplies use a step-down transformer to reduce the dangerously high mains voltage (230V in UK) to a safer low voltage.

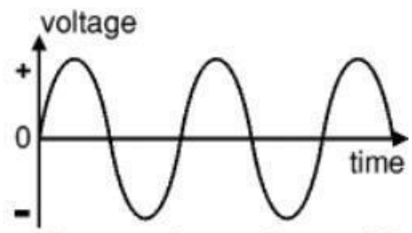
The input coil is called the primary and the output coil is called the secondary. There is no electrical connection between the two coils, instead they are linked by an alternating magnetic field created in the soft-iron core of the transformer. The two lines in the middle of the circuit symbol represent the core.

Transformers waste very little power so the power out is (almost) equal to the power in. Note that as voltage is stepped down current is stepped up.

The ratio of the number of turns on each coil, called the turns ratio, determines the ratio of the voltages. A step-down transformer has a large number of turns on its primary (input) coil which is connected to the high voltage mains supply, and a small number of turns on its secondary (output) coil to give a low output voltage.



Transformer



Output: low voltage AC

The low voltage AC output is suitable for lamps, heaters and special AC motors. It is not suitable for electronic circuits unless they include a rectifier and a smoothing capacitor.

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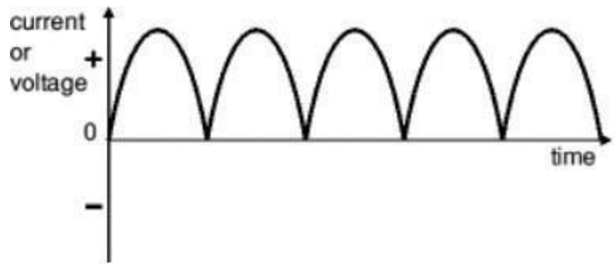
Rectifier

There are several ways of connecting diodes to make a rectifier to convert AC to DC. The bridge rectifier is the most important and it produces full-wave varying DC. A full-wave rectifier can also be made from just two diodes if a centre-tap transformer is used, but this method is rarely used now that diodes are cheaper. A single diode can be used as a rectifier but it only uses the positive (+) parts of the AC wave to produce half-wavevarying DC.

Bridge rectifier

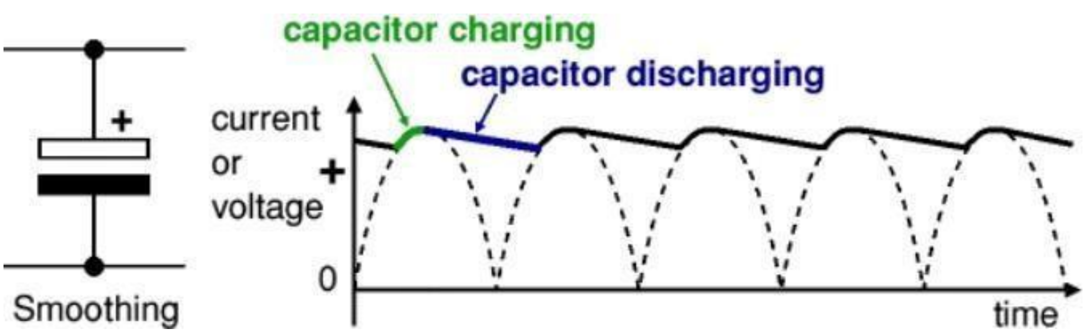
A bridge rectifier can be made using four individual diodes, but it is also available in special packages containing the four diodes required. It is called a full-wave rectifier because it uses all the AC wave (both positive and negative sections). 1.4V is used up in the bridge rectifier because each diode uses 0.7V when conducting and there are always two diodes conducting, as shown in the diagram below. Bridge rectifiers are rated by the maximum current they can pass and the maximum reverse voltage they can withstand (this must be at least three times the supply RMS voltage so the rectifier can withstand the peak voltages).

Please see the Diodes page for more details, including pictures of bridge rectifiers.



Smoothing

Smoothing is performed by a large value electrolytic capacitor connected across the DC supply to act as a reservoir, supplying current to the output when the varying DC voltage from the rectifier is falling. The diagram shows the unsmoothed varying DC (dotted line) and the smoothed DC (solid line). The capacitor charges quickly near the peak of the varying DC, and then discharges as it supplies current to the output.



Note that smoothing significantly increases the average DC voltage to almost the peak value (1.4 × RMS value). For example 6V RMS AC is rectified to full wave DC of about 4.6V RMS (1.4V is lost in the bridge rectifier), with smoothing this increases to almost the peak value giving 1.4 × 4.6 = 6.4V smooth DC.

Smoothing is not perfect due to the capacitor voltage falling a little as it discharges, giving a small ripple voltage. For many circuits a ripple which is 10% of the supply voltage is satisfactory and the equation below gives the required value for the smoothing capacitor. A larger capacitor will give less ripple. The capacitor value must be doubled when smoothing half-wave DC

$$\text{Smoothing capacitor for 10\% ripple, } C = \frac{5 \times Io}{Vs \times f}$$

Vs = supply voltage in volts (V), this is the peak value of the unsmoothed DC

f = frequency of the AC supply in hertz (Hz), 50Hz in the

CHAPTER 4

RESULTS AND DISCUSSION

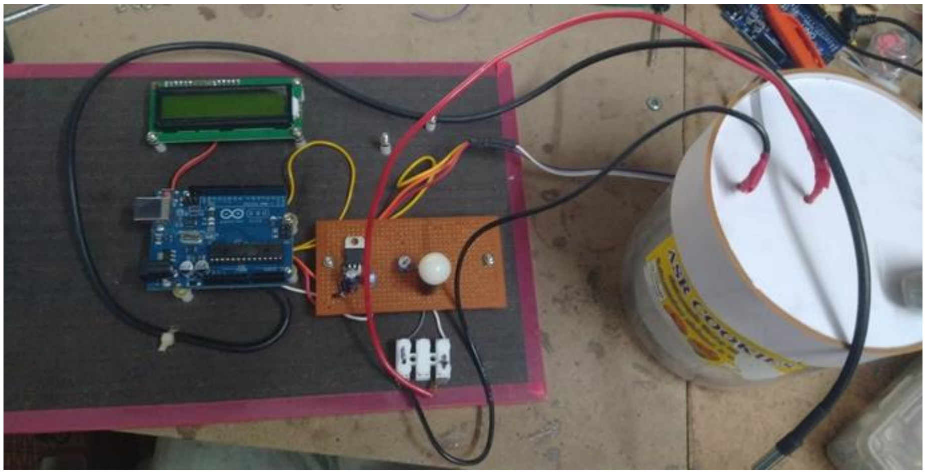


Fig. 4.1 Experimental Setup

The Fig. 4.1 represents the Experimental Setup of the Autonomous waste to wealth conversion. In this Experiment ,using the biogas the electricity is being generated. Because of the generated electricity the bulbs are glowing and the current voltage rating is shown in the DMM(Digital Multilmeter).This is the outcome of waste to wealth conversion of agricultural waste.

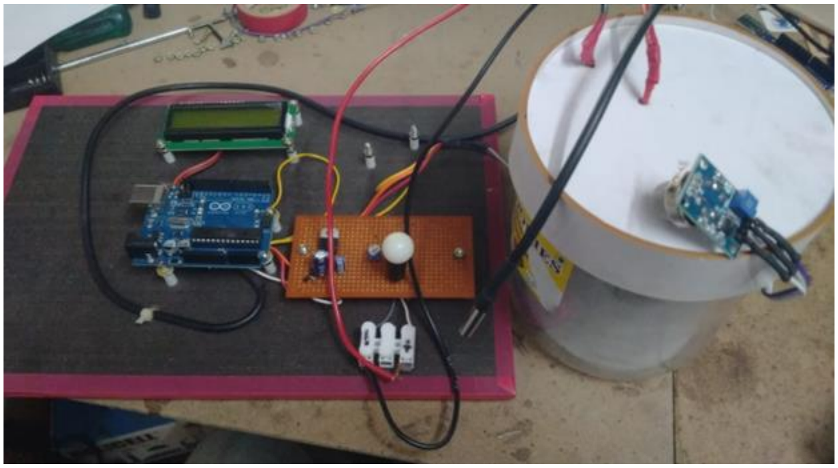


Fig 4.2 Circuit Connection

The Fig. 4.2 represents the Circuit Connection for the Autonomous Waste-to-Value Conversion project is built around an Arduino UNO, which controls and reads data from various sensors powered by electricity generated from biogas. A voltage sensor monitors generator output, while a temperature sensor ensures optimal digestion conditions.

An IR sensor adds environmental monitoring capability. Data from these sensors is displayed on a 16x2 LCD screen. The system is powered through a regulated 5V DC supply, derived from a 230V AC source using a transformer, bridge rectifier, and smoothing capacitor. A lead-acid battery stores excess energy for backup. All components are connected via jumper wires, enabling real-time monitoring and efficient energy use.

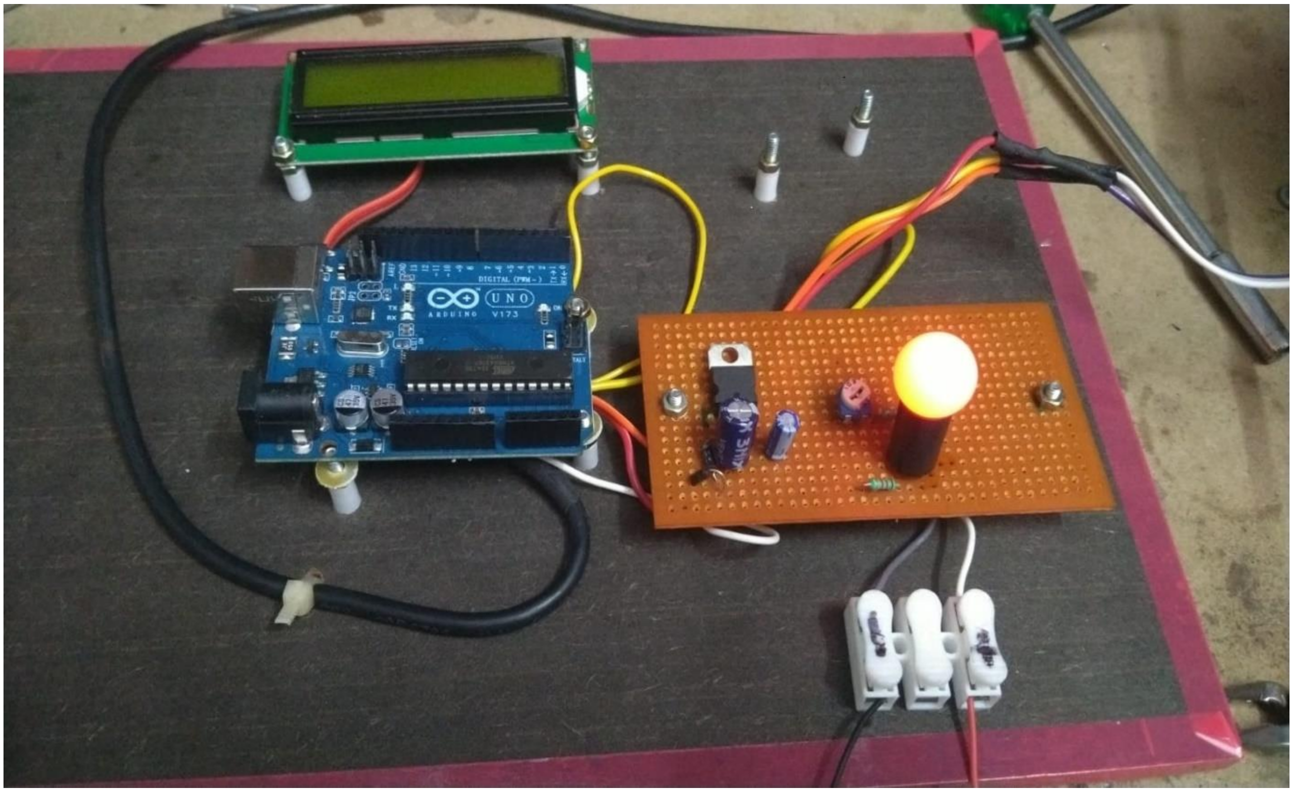


Fig 4.3 Output 1(LED Bulb Glow)

Fig.4.3 represents the Output of the Autonomous waste to wealth conversion. The above figure shows the LED Bulb glowing with the help of the electricity generated from the Biogas.

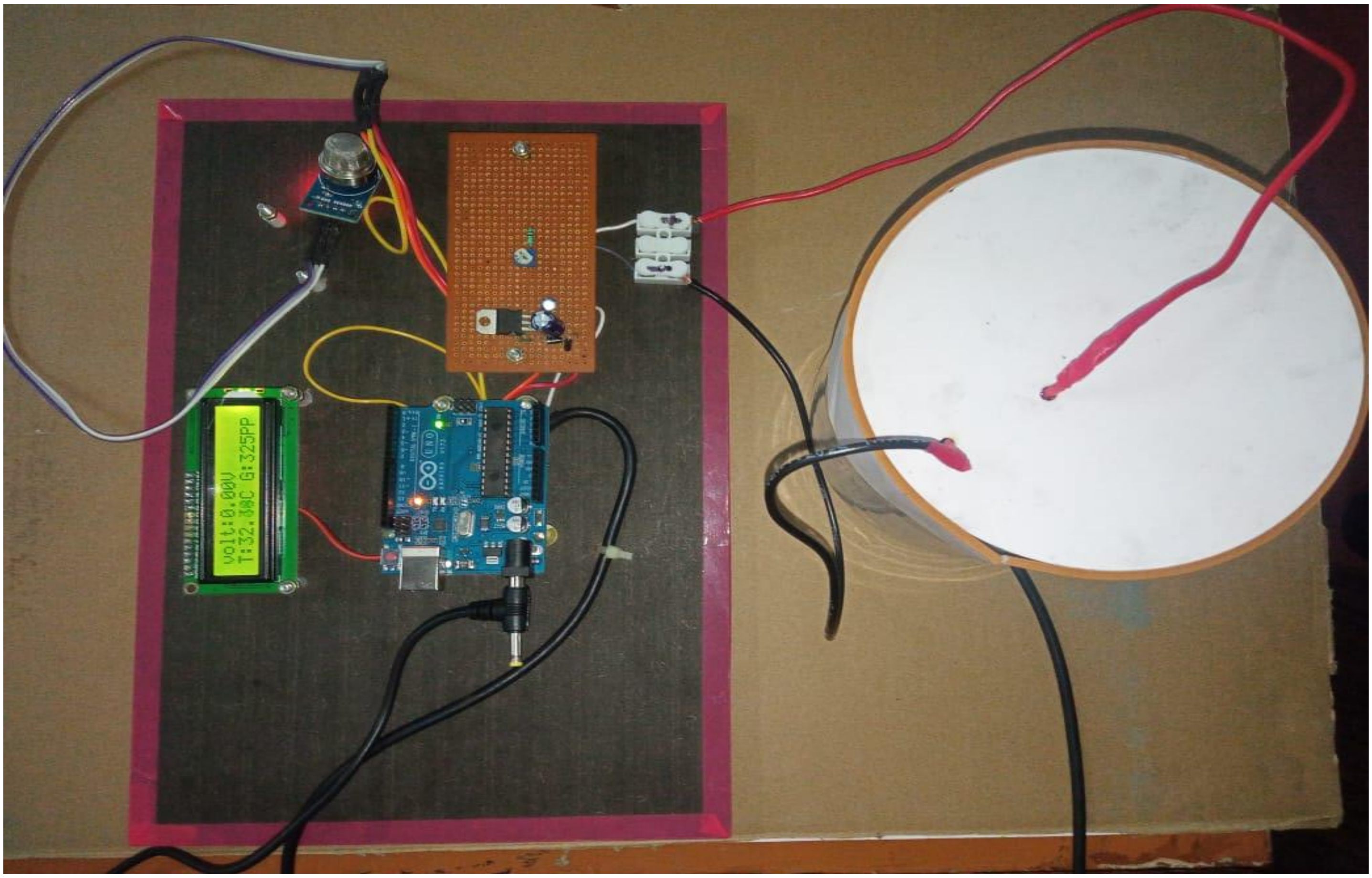


Fig 4.4.Output 2(LCD Results)

Fig.4.4 represents the Output of the Autonomous waste to wealth conversion. The above figure shows LCD Display being ON with the generated electricity from biogas.The LCD display shows voltage, temperature and gas.

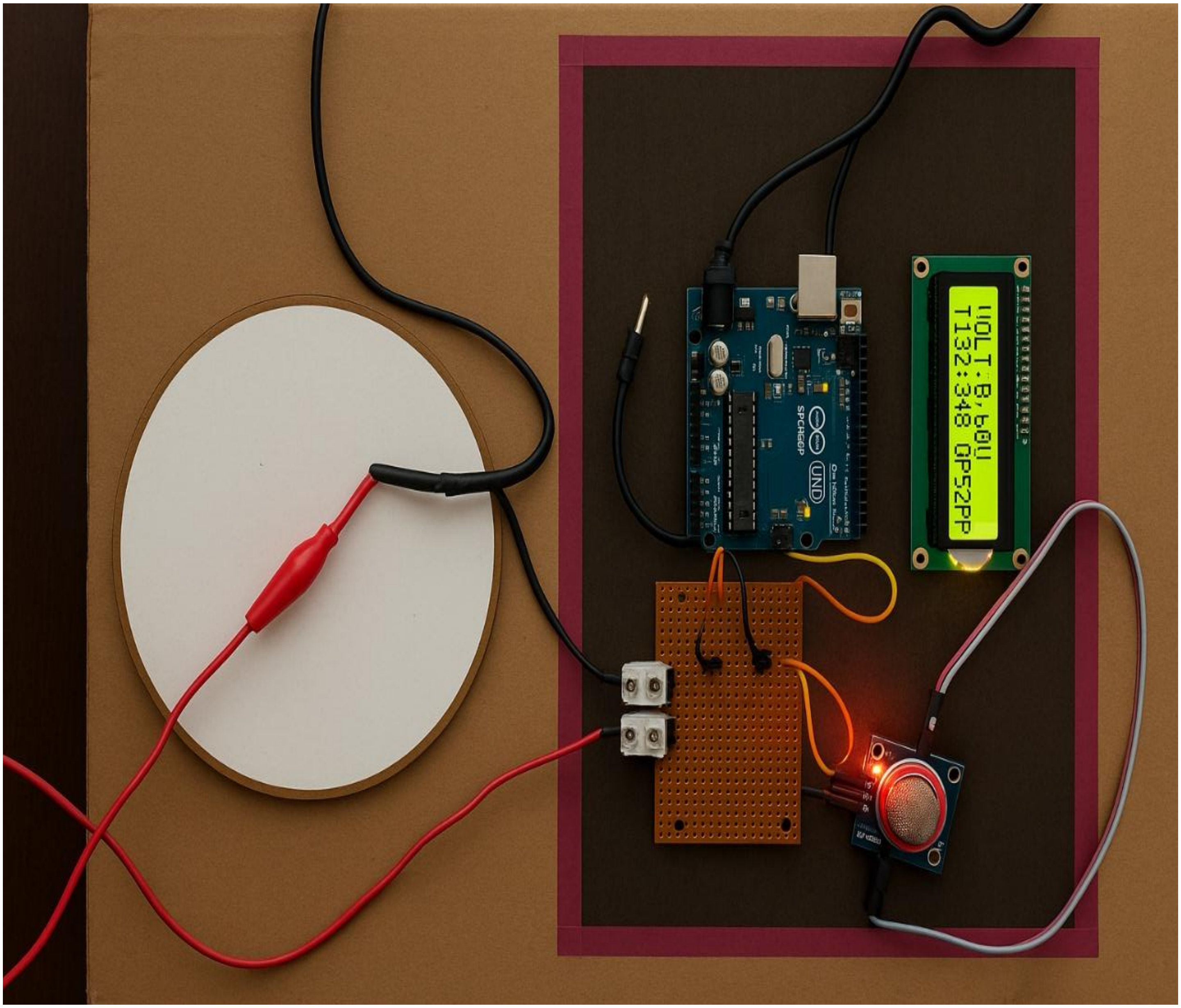


Fig 4.5.Output 3(Gas Sensor detecting the biogas)

Fig.4.5 Shows the result of the gas sensor that detects the biogas and shows the gas level in the LCD Display.

CHAPTER 5
CONCLUSION AND FUTURE WORK
CONCLUSION

The conversion of biogas to electricity represents a sustainable and efficient solution to multiple environmental and energy challenges faced by the modern world. Biogas, primarily composed of methane and carbon dioxide, is a renewable energy source produced through the anaerobic digestion of organic matter such as agricultural waste, food scraps, and sewage. Utilizing this resource to generate electricity not only reduces our reliance on fossil fuels but also helps in managing organic waste in an eco-friendly manner.

Biogas-powered electricity generation has the potential to contribute significantly to decentralized energy systems, especially in rural and off- grid communities. The technology involved—typically involving biogas collection, purification, and combustion in gas engines or turbines—is both mature and scalable. Additionally, the by-products of this process, such as digestate, can be used as nutrient-rich fertilizer, promoting circular economy practices.

From an environmental perspective, biogas electricity generation helps lower greenhouse gas emissions by capturing methane that would otherwise escape into the atmosphere. This makes it a powerful tool in the fight against climate change. Economically, it offers opportunities for job creation, energy independence, and cost savings on waste disposal and energy bills.

In conclusion, biogas-to-electricity systems provide a viable, sustainable, and environmentally responsible energy solution. With the right policy support, technological advancement, and public awareness, this approach can play a crucial role in the global transition toward clean and renewable energy sources.

FUTURE WORK

Develop smart, modular biogas-to-electricity units integrated with IoT for remote monitoring, automated waste feeding, and performance tracking. These compact systems can be deployed in rural areas, farms, and municipal waste centers, forming a decentralized microgrid.

They offer scalable, clean energy, reduce methane emissions, and support the circular economy—ideal for powering off-grid communities while promoting energy independence and sustainability.

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APPENDIX

```
#include <OneWire.h>
#include <DallasTemperature.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27 , 16, 2);   //7-5-23
// GPIO where the DS18B20 is connected to
const int oneWireBus = 4;

// Setup a oneWire instance to communicate with any OneWire devices
OneWire oneWire(oneWireBus);
// Pass our oneWire reference to Dallas Temperature sensor
DallasTemperature sensors(&oneWire);
void setup()
{
 Serial.begin(9600);
 lcd.init();
 lcd.backlight();
sensors.begin();
}
void loop() {
float s1 = (5.0* analogRead(0) * 10.0) / 1024;
 lcd.setCursor(0, 0);
lcd.print("volt:"); lcd.print(s1);lcd.print("V ");
sensors.requestTemperatures();
```

```
delay(100);
float temperatureC = sensors.getTempCByIndex(0);
lcd.setCursor(0, 1);
lcd.print("T:");
//lcd.print(sensorValue1);
lcd.print(temperatureC);
lcd.print("C ");
Serial.print(temperatureC);
delay(500);
// float s1 = (5.0* analogRead(0) * 10.0) / 1024;
int sensorData = analogRead(1);
// lcd.setCursor(0,1);
lcd.print("G:");
//lcd.setCursor(0,);
lcd.print(sensorData, DEC);
lcd.print("PPM");
}
```