

# PROJECT PROPOSAL

ON

**To design, develop and demonstrate a 1kW exhaust-assisted gasifier with bagasse as biomass and hydrogen-powered fuel cell**

Submitted To

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By

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# **To design, develop and demonstrate a 1kW exhaust-assisted gasifier with bagasse as biomass and hydrogen-powered fuel cell**

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## **Summary** **(About a paragraph)**

The proposal aims to employ sugarcane bagasse as biomass to produce hydrogen-rich producer gas by employing steam-air gasification in a fixed bed gasifier. The pure-hydrogen is then envisaged to be extracted from the producer gas to feed fuel cell to produce power. The exhaust of the separator (after separating pure-H<sub>2</sub>) is proposed to be employed by (a) extracting its heat in a heat exchanger to preheat incoming air to the gasifier and (b) to combust it to extract heat for steam generation as well as to provide heat required for the gasification as an external source. This exhaust-assisted gasification has not been reported before. The proposal aims to develop a 1 kW exhaust-assisted gasifier as a proof of concept and then scale it to produce a 10kW field demonstration unit.

## **Need of the Project with proper** **(assessment for viability of the product/ outcome)**

Fossil fuels like coal and petroleum are dwindling fast and their detrimental effect on the environment is a cause for grave concern. The menace of global warming led by greenhouse gas emission, climate change needs to be addressed now. Biomass is third among the primary energy sources available after coal and oil. Biomass consists of forest biomass comprising deadwood and residues and agriculture biomass comprising crop residues. India produces 686 MT gross crop residue biomass per year. Out of this, 34% of gross (i.e., 234 MT) are estimated as surplus for bioenergy generation. This is estimated to have the capability to produce 4.15EJ of energy (1 EJ= 10<sup>18</sup> J), equivalent to 17% of India's total primary energy consumption [1].

In 2014, dry residue produced by sugarcane in India was 107.5 million ton/year, only behind rice and wheat [1]. It contributed to 17% crop residue generated. With 20% ethanol blending planned by 2030 in IC engines[2], and the government allowing sugarcane for ethanol production, the sugarcane-based ethanol production capacity is expected to increase by 78%. This will motivate more farmers to grow sugarcane which could consequently produce much more than the present levels of sugarcane residue (bagasse). As such, bagasse as an agriculture residue excellently

qualifies to be employed for gasification.

Fixed-bed gasification is a well-established technology for biomass gasification [3-38]. Both air and steam as gasification medium have been studied and implemented in the past. As the present proposal aims to employ this technology the viability of the product is clearly established. The novelty in the present work is the utilization of exhaust gas of the H<sub>2</sub>-separator to assist the gasification process by preheating the gasification mediums and providing heat required for gasification externally to the gasifier.

Preliminary calculations show that for 1 kW of fuel cell-power generation, the composition from the H<sub>2</sub>-separator (H<sub>2</sub>/CO/CO<sub>2</sub>/CH<sub>4</sub>/N<sub>2</sub>) is such that there are significant portions of combustible components still present. According to the estimate (shown later) around 0.5 kW of energy would be available after accounting for (a) heating incoming air and (b) producing steam at 150 °C from water at 25 °C. This energy if properly utilized can be transferred to the gasifier as external heat to make it semi-allothermal (some part of temperature rise required for gasification comes from external source instead of burning of biomass which is autothermal mode). Thus, this exhaust-assisted gasification is viable and the resulting gasifier would be novel.

### **Work at National Institutions**

In Indian context, some of the first works on biomass gasification began in 1981 at IISc by Prof. Mukunda and team. The pioneering works at the Centre are now being carried forward by Prof. Dasappa and team. A 5 kW open-top wood-driven gasifier-engine setup was first developed in India in 1985 by this group [3]. In 1994, a 100 kW<sub>e</sub> with an open core reactor, a cooling and a filtering system along with a blower and a burner was developed [4]. Oxy-steam gasification to produce H<sub>2</sub>-rich syngas in an improved version of open-top downdraft gasifier was first reported in 2014 by this group [5]. Methanol synthesis from agri-residue using oxy-steam gasification in the same gasifier is reported very recently (2022) [6].

At various other places across the country there have been seminal works carried out in the area of fixed bed gasifiers. For instance, Bhoi et al. [7] experimentally investigated a 625 MJ/h open top, throat-less reactor with babul wood, groundnut shell briquette to conclude that cold gas efficiency depended on biomass feedstock. Same type of reactor was also investigated by Singh et al. [8] and Vyas et al. [9]. A 75 kW<sub>th</sub> throat type downdraft gasifier was investigated to study the effect of gasification temperature [10]. Sheth and Babu [11] studied dependence of moisture content of wood chip in an Imbert type gasifier. Patel et al. [12] employed fixed bed gasifier for gasification of lignite.

Prof. Panwar and group have studied the open core downdraft gasifier in the context of food processing industry, domestic and agro-industrial application [13-14]. Prof. Chaurasia and group have reported both experimental and numerical studies in the area of high-ash biomass like rice husk and its tar cracking [15-16].

At IIT BHU, significant work has been done in the area of downdraft gasifier-powered engine power generation [17-19]. A 14 kW<sub>th</sub> downdraft gasifier is in use since 2015 and till date is being employed in major research activities.

At IIT Bombay, Prof. Mahajani and team have investigated high ash biomass and high ash coal co-gasification in a downdraft gasifier. Their recent paper on effect of gasification zone length on the performance of gasifier is insightful [20-21].

At IIT Delhi, Prof. Ravi and Prof Kohli's teams are actively researching on downdraft gasifier, both experimentally and numerically. Particularly, their seminal works on employing a downdraft gasifier to design a cookstove is noteworthy. In addition, their modelling studies have significantly enhanced knowledge of fluid and heat transfer in these gasifiers [22-24]

At IIT Guwahati, downdraft gasifier has been one of the investigating areas of Prof. Moholkar and Prof. Mahanta's teams [25-26].

### **Work at National Industries**

Cummins India Ltd. and Thermax Ltd. led by Prof A Ganesh and Dr Sonde respectively have installed multi kW gasifiers across India for rural electrification, industrial application etc. In addition, M/s Bioresidue Energy Technology Pvt. Ltd., M/s EnergreenPower Ltd., M/s Arrya Hi-Tech Energy and M/s NetPro RenewableEnergy (India) Pvt. Ltd, M/s AnkurScientific Technologies Ltd., M/s Urja Gasifiers are actively involved in manufacturing and installing fixed bed gasifiers for MSME sectors based on designs from IISc, IIT Bombay, TERI etc.

### **Work at International level**

Fixed bed gasifiers of throat type [27-30] and throatless [31-33] have been investigated by international investigators.

Liinanki, et al, [34] employed downdraftgasifier with a rotating grate and a double conical hopper to gasify coir dust, cotton stalk and wheat straw. Yang, et al., [35] investigated high temperature agent gasification (HiTAG) of woodpellets in a batch type updraft fixed bed gasifier. Na, et al., [36] employed O<sub>2</sub> gasification medium gasify combustible waste pellets in an updraft fixed bed gasifier linedwith alumina refractory. Barrio, et al., [37] used a small-scale (30 kW) stratified downdraft gasifier to gasify wood pellets. In 2003, Jayah et al., [38] investigated the gasification process of rubber wood of varying moisturecontent (12.5-18.5 %) and chip size in an 80 kW downdraft throated gasifier.

To summarize, fixed-bed gasification is an established technology with air, steam, oxygen, CO<sub>2</sub> as gasification mediums. A number of agro-residues/biomass have been used. However, majority of the gasifiers have been operated in autothermal mode i.e., the heat required to raise the temperature for gasification comes from combustion of biomass (usually 30%) initially. This leads to contamination of producer gas. The present proposal aims to minimize the autothermal contribution by preheating the incoming mediums and providing a significant part of heat required for gasification externally to the gasifier.

Detailed methodology including schematics, diagrams, all relevant technical details and rationale etc.

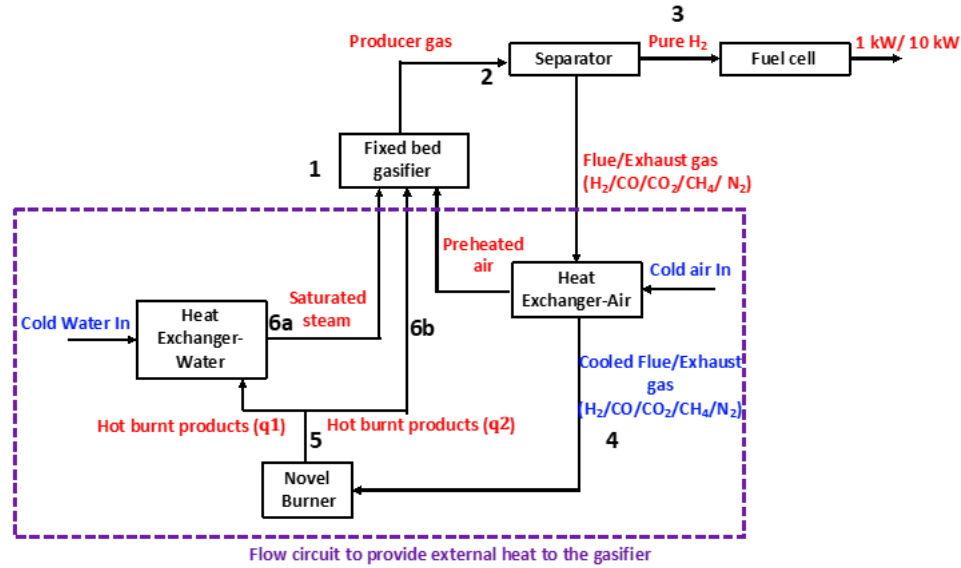


Fig. 1. Schematic of exhaust-assisted biomass gasification process for biohydrogen generation

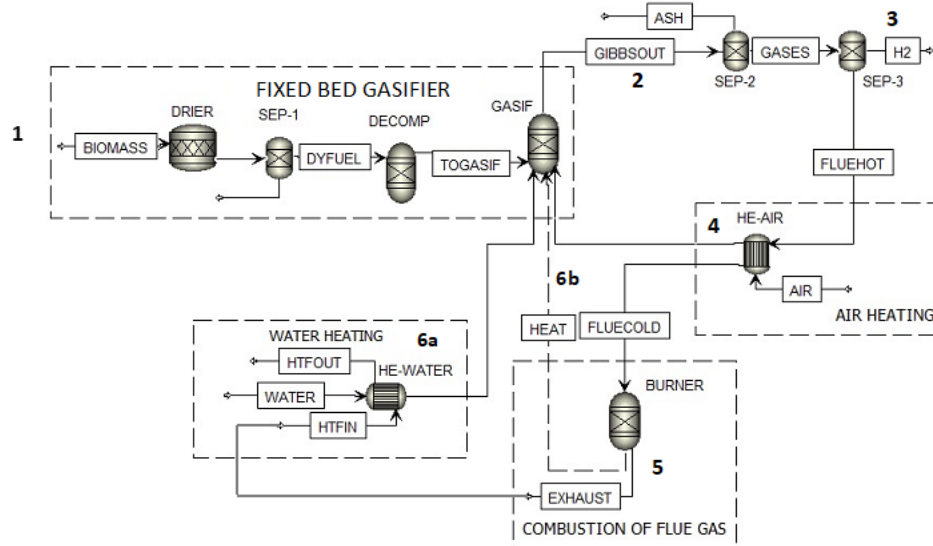


Fig. 2. ASPEN Plus flowsheet of exhaust-assisted biomass gasification for biohydrogen generation

The envisaged exhaust-assisted biomass gasifier for production of biohydrogen using agriculture residues is schematically shown in Fig. 1. The same has been shown as ASPEN Plus flowsheet in Fig. 2. The overall process consists of: (a) gasifying the agriculture residues in a bubbling fluidized bed gasifier (1-2) (b) separate pure H<sub>2</sub> from the producer gas (2-3) and employ fuel cell for power production using the separated pure H<sub>2</sub> (c) employ exhaust of the separator block (which still consists of at least 11% H<sub>2</sub>) to preheat air (3-4) (d) combust the exhaust in a novel

burner (4-5) to generate steam for the gasification (5-6a) (e) also use the leftover heat from the exhaust (5-6b) to provide the heat required for gasification as an external source to continue the gasification process. This overall cycle would comprise of following work packages (WP):

#### Preliminary work/calculations

The preliminary calculations are done for design and development of a 1 kW gasifier that would be developed at lab-scale as a proof of concept. Later, the same calculations will be scaled for 10 kW field demonstration unit. The agriculture residue that will be used is sugarcane bagasse as it is relevant to Indian scenario.

As preliminary work/calculations, the gasification process for bagasse is simulated in ASPEN Plus software with 10% moisture content (Fig. 2). The idea is to generate 1 kW (for the lab-scale demonstration plant) of power using fuel cell (FC) running on pure H<sub>2</sub>. Then the plant would be scaled to 10 kW for practical utility.

A 1 kW FC power mandates producing around 10 lpm of pure H<sub>2</sub> from the producer gas. The calculations have been done keeping this in mind. The amount of biomass, gasifying medium required have been calculated according to this estimate.

The gasification has been simulated using air and steam as two gasifying mediums to depict the two extremes i.e., wholly-air and wholly-steam. The composition of the producer gas (a mixture of H<sub>2</sub>/CO/CO<sub>2</sub>/CH<sub>4</sub>/N<sub>2</sub>) at different gasification temperatures at different equivalence ratio (ER) for air and molar steam-to-biomass ratio (SBR) for steam are shown in Fig. 3. The producer gas composition is predicted by minimizing the Gibbs free energy in the reactor. The gasification model has been validated from the previous works [38-39] and is not shown here for brevity. The proximate and ultimate analyses of bagasse required for the calculations are taken from [40].

#### **Proposed cost:**

| Sl. No. | Item                          | Total Cost (In Rs.)   | First Year | Second Year |
|---------|-------------------------------|-----------------------|------------|-------------|
|         |                               |                       |            |             |
| 1.      | Equipment                     | 40,0000               | 225000     | 175000      |
| 2.      | Consumables                   | 50,000                | 25,000     | 25000       |
| 3.      | Contingencies/<br>Other Costs | 40,000                | 20000      | 20000       |
| 4.      | Travel                        | 10,000                | 10000      | 0           |
| 5.      | Grand Total                   | <b>Rs. 50,0000=00</b> | 330000     | 220000      |

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