Short History of Biomass Gasification at NARI

(Chapter from the book "Romance of Innovation")

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When I came back from the U.S. in 1981 to live in Phaltan – a sugarcane-growing area in western Maharashtra, my first impression of the area was seeing the night sky lit up with fires! All the sugarcane farmers, after harvesting the sugarcane crop, would burn the sugarcane trash (leaves left after harvest) in the field in a commonly accepted method of waste disposal. Not only was this a tremendous waste of energy but the burning also polluted the clean rural air. There are estimates that this open field burning of agricultural residues produces brown haze over the Indian subcontinent and maybe responsible for weather modification in this region. Hence I thought about what could be done to produce useful energy from sugarcane trash (mostly consisting of dried 0.3-0.5 m long leaves).

Power for water pumping was a major necessity in rural areas and in those days the use of 5 horsepower (HP) diesel pump sets all over the country was in vogue. So, the question was how to use the energy of sugarcane leaves for pumping water. There were many competing technologies for this and I developed a method of evaluating them based on the Energy Index (EI) concept.

EI is basically a ratio of the total amount of energy produced by the device in its lifetime to the sum of total energy used in its manufacturing and the energy consumed in running it during its lifetime. Hence the higher the EI the better is the technology energy wise. Producer gas-based units had the highest EI and hence we focused on developing biomass gasifiers.

A biomass gasifier is a device which converts dry biomass (wood, leaves, twigs, etc.) into high quality producer gas (a mixture of carbon monoxide and hydrogen). This is achieved by burning the biomass with less oxygen in a suitably designed reactor. The producer gas so produced contains tars, char and fine dust and hence after being cleaned with suitable filters can be used to produce electricity via petrol and diesel engine gensets. The cleaning of the gas is very difficult, costly and requires elaborate filters. In case it is not suitably cleaned (which is the case most of the time) then the gas can be used in burners for thermal applications like fuelling furnaces and boilers.

During my U.S. days I had interacted with one Professor John Goss at University of California, Davis. He and his students had developed the first open-top, throat-less rice husk gasifier. In this type of gasifier the biomass is fed into the reactor (basically a metal tube and hence the name throat-less) from the top; it is combusted inside the tube, resulting in the production of the gas. I thought that sugarcane leaves could also be gasified in a similar gasifier.

In 1983 I wrote a small proposal for developing small sugarcane leaves gasifier and submitted it to the Department of Non-Conventional Energy Sources (DNES), Government of India, which was the predecessor of the present-day Ministry of New and Renewable Energy (MNRE). The director of DNES told me that when even large organizations like the Indian Institutes of Institute of Technology (IIT) and Indian Institute of Science (IISc) had not been able to gasify loose leafy biomass, how would a small one like NARI, with very little resources, be able to do it? He suggested I focus on wood instead. He told me to convert the sugarcane leaves gasification proposal to one with a small-scale wood gasifier running a 5 HP diesel engine.

NARI's first gasifier. 1984-85

In a way this was a good suggestion because in developing this gasifier we gained lots of experience; it also allowed me to assemble a good team for our future work.

Our work on the wood gasifier started in 1984. In fact we were among the pioneers of gasification in India. Five groups were given funding for gasification research in 1984 by DNES - IIT Delhi, IIT Bombay, IISc Bangalore, Ankur Scientific in Baroda, and NARI. Ours was the only group with very limited fabrication facility, and raw, inexperienced staff. Yet, with dedication and by continuously working on the gasifier problems we gained valuable experience.

Meanwhile, in 1986 I also wrote a chapter on gasification in a book published by CRC. In it I wrote about the basics of gasification science and technology and included a section on the status of technology worldwide in 1986. The book acts as a primer for the people who want to learn about gasification and is one of the most quoted biomass gasification books on the internet.

For gasification systems to become successful it is necessary that the producer gas should be made completely clean so that the diesel or petrol engine can run on it continuously for at least 5,000 hours without the need for cleaning and overhauling.

However our work in small-scale wood gasification showed that it was extremely difficult to cool and clean the gas. This is primarily because the tar, which contains more than 200 different chemicals, is difficult to remove with the help of only a few solvents. And secondly the very fine dust in the gas mixes with the tar to make a gooey mixture which gums up the filters and engine intake valves. This necessitated continuous cleaning of the engine. I feel that even today the problem of cleaning the gas persists and has not been satisfactorily solved in any gasifier sold in the market.

Nevertheless we persisted in our efforts and spent quite a lot of effort and time on cleaning the gas from our small scale sugarcane leaves gasifier and ran a 15 kVA diesel genset on it for almost 1000 hours. However, the gas cleaning system itself required constant maintenance, resulting in downtime of the system and thus was not user friendly. We therefore decided that the best course of action would be to develop sugarcane leaves gasification technology for thermal applications only.

We also made a conscious decision that for low-density loose leafy biomass material like dry sugarcane leaves the best way to gasify them would be to run the gasifier in pyrolysis mode (running at gasification temperatures of <900^{o}C). Also the biomass input and char removal was done continuously. This allowed the biomass to flow smoothly inside the reactor and without clinker formation.

By the early 1990s we had gained enough experience regarding the issues of gasification and in 1991 I presented a paper at the annual gasification workshop in Vadodara outlining what needs to be done in gasification research in India. The call was to do more R&D in improving gasification efficiency, cleaning of the gas and in producing liquid fuels from biomass. Unfortunately, little progress has been made in gasification in India and the issues outlined in that paper are still relevant today.

L-R: D.B.Jadhav, A.M.Pawar, S.M.Patil, D.B.Gadhave, Rajiv M. Jorapur. Photo taken in late 1993.

Our work in sugarcane leaves and other leafy biomass gasification started in 1987 and culminated in 1997 when we developed a 500 kW thermal gasifier with funds from the Rockefeller Foundation. The work started with a one meter tall 15-20 kW thermal gasifier and the final design of a 500 kW thermal gasifier was the 4th generation unit. But then I am getting ahead of my story.

The icing on the cake for our work was when one of the leaders in gasification technology, a professor from IIT Delhi, came and saw our work on sugarcane leaves gasifier in 1992 and said that we had done what all the IITs and IISc could not do. In fact there are good indications that quite a number of reputed national institutes went on to copy our design in later years!

The reason we were able to achieve success in our design was not because we were more intelligent than the rest – it was purely because of hard work. We continuously modified, changed and tested every component of the system till we were successful. Though we were a small rural NGO with very limited resources we were able to develop the first such gasifier in the world because of excellent team work.

Also in all our gasification and other work we used very simple equipment and in some places improvised on the existing ones to get good data.

For example we set up online an inexpensive Junkers Calorimeter to measure the gas quality continuously. A more fancy and costly equipment of on line Gas Chromatograph with calorific value analyzer could have done the work easily but to maintain it and service it in rural environment would have been quite difficult.

Similarly we developed very simple filters to measure the particulates in the gas by going to the basic science of measuring the gas flow rate and the amount of particulates deposited on a filter. This gave us very good idea about the loading of gas and effectiveness of our filtering system.

Too often I have found that scientists buy fancy equipment which is hardly used; besides it is necessary to have a fully qualified technicians to use and maintain it. Thus in lots of labs very fancy and costly equipment simply sit on the desk as showpiece .

I believe that with simple equipment one understands fully well what one is measuring and the limitations of the measurement process. A fancy equipment masks the limitations and also needs constant calibration. This does not mean that we should not use sophisticated equipment but then the user should know thoroughly what the equipment is capable of measuring and its limitations. Today most of the research workers do not have the time or the inclination to do so.

We presented our work on sugarcane leaves gasifiers for electricity generation in May 1992 when I was invited to the third European Biomass Energy Conversion Conference held in Interlaken, Switzerland.

It was a small conference with around 100 participants but almost all the who's who of the world in the area of biomass energy were there. I was the only Indian participant. This conference gave me an exposure to the latest work in biomass energy conversion and I was introduced to the technology of pyrolysis oil production from biomass. Basically it involves combusting the biomass in even less oxygen than needed for gasification and then to condense the ensuing gases to produce the oil. This pyrolysis oil is similar to diesel and with suitable modifications and processing via catalysts can be converted into automobile fuel.

In 1992 this technology of pyrolysis oil was very new and all the people (only three groups) involved in its R&D in the world were present at the conference.

I saw a tremendous opportunity for India to produce its own oil from biomass. I had lengthy discussions with the developers of the technology, and they said that they would transfer all the intellectual property rights to an Indian entity at a lump sum cost of quarter of a million dollars. For a country like India this money was peanuts.

I came back from the conference all charged-up, and discussed the whole issue with DNES officials, but got a very lukewarm response. It seemed they did not understand the technology and its implications. So, in desperation and youthful exuberance I wrote a five-page letter to Mr. Narasimha Rao, the Prime Minister of India at the time. Mr. Rao was well-known for never replying to letters even from his closest colleagues let alone from an unknown Indian from the rural area, and hence I was not hopeful about receiving a response. Yet, within 20 days I got a personal letter from him thanking me for bringing the issue of pyrolysis oil technology to his attention. The letter also mentioned that he was sending it to DNES for further action.

Immediately I got a letter from DNES asking why I had approached the Prime Minister! They informed me that this was an old technology that they were aware of and even had R&D projects on! All of this was not true and hence nothing came out of my suggestions.

I felt India lost a tremendous opportunity to develop a national program on pyrolysis oil from agricultural residues. Today, production of pyrolysis oil world over is an important part of renewable liquid fuels, the technology is proprietary, and the technology transfer fees are very high.

Finally, just two years ago, MNRE woke up to the potential of this oil and for the first time put out a request for proposal (RFP) for developing a pyrolysis oil program. We thus lost 20 years in developing this technology!

Pyrolysis oil and gasification are closely related and I felt if we had introduced a national program in pyrolysis oil 20 years ago, it would have also strengthened the gasification program, which is now floundering.

The Biomass Energy Conference in Interlaken-a beautiful resort in Switzerland also provided me an opportunity to see Switzerland. One day in the afternoon (it was half a day off for the conference) I walked around the lake Thum and climbed a nearby hill from where the snow-clad peaks of Jungfrau and other Swiss Alps were visible. It provided a wonderful view and was a spiritual experience. So smitten, I decided to travel through Swiss Alps more thoroughly after the conference. I and Nandini had visited Switzerland in 1981 but had not travelled around to see the natural beauty of the Alps.

In the month of May Interlaken was quite cold and it was even cooler in the nearby hills. I somehow misjudged the weather and was not adequately dressed for the cold weather and so caught a cold. Normally I carry with me a homeopathic medicines kit but found that Aconite (the medicine for cold) had finished. So I went to the nearest homeopathic shop in Interlaken and asked for the medicine. The shop keeper quoted 10 Swiss francs for it. At that time it was equal to about Rs. 250/-. In India the same medicine was available for Rs. 2-3 only. On hearing this price my cold suddenly became alright!

After the conference I visited my friend in Basel. She suggested that to see Swiss Alps I should buy a three-day Swiss train pass with reservations on the Glacier Express – a train which took you through all the main points in the Alps.

This three-day trip was a fantastic journey through the Alps. Not only did I see the wonders of Swiss Railways but also sampled the chalets in different Swiss villages. Thus I would get down at any station which I liked, visit the town and after a couple of hours come back to the station and again get on the next Glacier Express. Also in these three days I did not see a single Indian. In those days very few Indians travelled on such routes. Nowadays there is not a single place in the world where you will not see the Indian tourists.

I also saw how on steep slopes the trains with the help of gears (ratchet and pinion) climbed; something which is unthinkable even today in India. This climbing of steep slopes reduced the distance the trains had to travel to reach their destination. In India and other places the trains can only climb a hill by going around it in gradually increasing slope.

Also in three days I must have travelled in about a dozen trains and yet not a single train was ever late and one could actually set one's watch by the train's arrival timing-a classic case of Swiss efficiency and time accuracy!

However in one leg of the Glacial express journey we had to cross over to northern Italy. In this journey the train was late by one hour! We also stopped at an Italian station which was as filthy as Indian stations! Thus from the heaven of Swiss system I felt as if I was suddenly transported home to India! That is when I also realized how similar India and Italy are!

I thoroughly enjoyed my Swiss travel and have always used the opportunity of conference attendance to see the natural beauty of that county.

Based on our work on a small-scale sugarcane leaves gasifier, the Rockefeller Foundation, New York gave us a grant in 1993 to develop a thermal gasifier for industrial application. The idea was to replace the furnace oil-based furnaces and industrial heaters by the gas from this type of gasifiers. Taking the actual industry requirement into consideration, we decided to develop a sugarcane leaves gasifier of 100-500 kW (thermal) capacity. Till that time our biggest gasifier was a 70-80 kW (thermal) unit and to scale it up to 500 kW was quite a task.

Sugarcane leaves gasifier at NARI. 1996

Nevertheless the team took up the challenge and in two years we developed our first model of automated and PLC-controlled 250 kW (thermal) gasifier. It was a great achievement and after successfully testing it in a Pune-based company manufacturing ceramic tiles, we scaled it up to a 500 kW (thermal) gasifier, which is presently at our campus.

This multifuel gasifier (it ran on loose sugarcane leaves, sugarcane bagasse and other low density biomass) not only produced useful thermal energy via the production of gas but also produced char (25% by weight of biomass). We used this char in the fields to gauge its effect on crop yields. Today the use of biochar in farming is common, but I think our work in 1993 was the first serious attempt anywhere. A photograph of our work on biochar graced the cover of the *International Journal of Biomass and Bioenergy (Vol 13, No. 3, 1997)*.

Gasifier powered syrup making furnace, 1995

We also used this gasifier to run our sweet sorghum syrup production unit. This showed that gasifiers can be used for large scale community cooking provided the gas burners are in well ventilated areas. Producer gas contains about 10-15% carbon monoxide (CO) - a lethal gas. Hence the burners should be in ventilated areas so that the cook is not exposed to this gas. We also developed small ruminants (sheep) disposal units using the gasifier and were able to burn one dead sheep in under an hour. We feel that biomass gasifiers maybe used in future for human and animal cremations.

One of the major issues in developing loose leafy biomass gasifier was the transport of low-density biomass from the fields to the gasification unit. To reduce the transportation cost we felt that biomass needs to be compacted. In those times (early 1990s) there were no baling machines available in India. So we discussed with the farm machinery manufacturers in India a need to develop such machines but they were not interested because they did not see the market. Importing a machine from abroad was very costly. Even today there is a great challenge to develop baling machines for agricultural residues since these residues are becoming an important resource for power generation and composting.

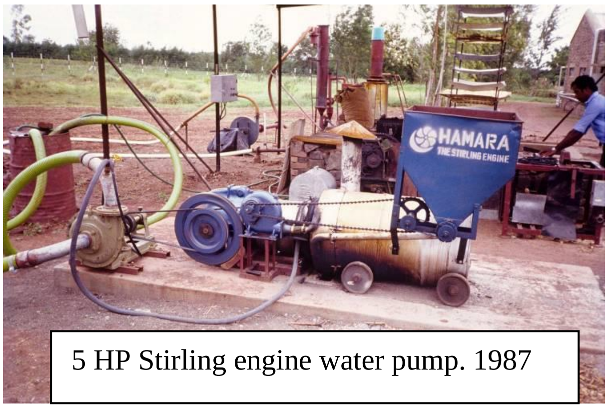
I believe we were highly successful in designing and developing the sugarcane leaves gasification system for thermal applications. However our failure was that we were not successful in marketing it. One of the reasons was that we were almost 10-15 years ahead of time; in the late 1990s very few people were interested in it. And secondly it was not economically viable in those times. Now with increasing oil prices and shortage of electricity in India there is a renewed interest in providing thermal and electricity options from locally available biomass resources. Thus there seems to be a renewed interest in thermal gasification systems in India and world wide and we get regular inquiries about our gasifiers.

However I still feel that the biggest challenge is how to efficiently and thoroughly clean the gas for power generation. This is an area for further R&D.

Another area that we worked in was the direct combustion of wet bagasse for small furnaces (ICAR funded). These furnaces are used in many applications in rural areas like jaggery making and other heating applications. Most of the times the biomass available is wet. So we designed and developed one such furnace where the wet biomass was fed in the furnace where it was dried and then the dried biomass was burnt. This interesting work needs to be further researched and modified.

Though we did lot of work on biomass gasification another attractive technology for motive power in rural areas is stirling engine. Stirling engines are external combustion engines in which heat from any source can be used to run them. Mostly their working fluid is air. Their efficiencies are poor and though they were invented almost 120 years ago, have never reached their full potential. The main problem has been with the design and materials of heat exchanger which has to rapidly transfer heat between hot and cold cycle.

I was familiar with their design and working since our lab in University of Florida was well known for its work on solar powered stirling engines. So when in early 1980s we were gifted a "Hamara" stirling engine by Maharashtra Energy Development Agency (MEDA), I eagerly looked forward to testing them. This engine was manufactured by a party in Madras (now Chennai) under license from Sunpower Inc – a US based company.



5 HP Stirling engine water pump. 1987

The simple "Hamara" engine (pictured) had efficiency of only 1-2%, was very heavy, expensive and costly to run. That was the main reason why it never took off despite its attractive feature of running on any heat source.

Recently there are indications and claims by some manufactures that with new materials and manufacturing technology (3D printing) for making heat exchangers, their efficiencies have improved. However only time will tell whether these claims will stand in the marketplace.

Future research areas

1. Most of the issues for future R&D in gasification were discussed in my idea paper given in 1990 at Vadodara. Those issues are still valid. Basically they are cleaning of gas and making small continuous gasifiers.

2. Besides gasifier there are many streams through which agricultural residues can produce energy. Biogas reactors or digesters are one such route. They can produce methane from fresh residues to drive internal combustion engines and the slurry from the digester is an excellent fertilizer for the soil. Increasing fertility of the soil is one of the main activities of farming. The fertility can also be increased by directly incorporating the agricultural residues in soil. However in that process precious methane is lost to the atmosphere and cannot be used as an energy source.

   The challenge is to produce very efficient and continuous biogas digesters running on agricultural residues and design engines to run on them. Existing diesel engines are quite suitable to run on biogas but require improvements to increase their efficiencies.

3. For producing high quality energy there is a challenge of converting agricultural residues to liquid fuels like petrol and kerosene. These can power the existing internal combustion engines for rural mobility, farm machinery and electricity generation.

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