The novel research described here takes tobacco stem, a byproduct residue from cigarette manufacturing, recycled at the source for pyrolytic conversion to obtain a gaseous fuel and biochar that can be used as alternatives for natural gas and activated carbon.
In 2014, worldwide cigarette sales reached approximately 120 million cartons. China is both a major tobacco producer (approximately 3.4 million tons of tobacco annually) and a vital consumer (accounting for roughly 30 percent of the cigarette sales worldwide). During the cigarette manufacturing process, the tobacco leaf is baked to remove any moisture and to more easily separate the lamina from the main stem. The stem itself accounts for more than 20 percent of the tobacco leaf’s weight, but is considered useless in the production of tobacco products and is typically discarded as waste.

Properties and Applications of Tobacco Stem

In China, approximately 1 million tons of tobacco byproduct residue is generated annually—this figure expands to over 11 million tons globally—of which almost half ends up in landfills. If not properly handled, serious resource waste and environmental problems could occur, including soil and water contamination, as nicotine, a toxic matter with high solubility in water, is hard to contain once leaching occurs.

The physical and chemical properties of tobacco are influenced by many factors, including genetics, soil type, and climate. The tobacco stem, a lignocellulosic biomass, is primarily made up of cellulose, hemicellulose, and lignin, coupled with an approximate 10 wt.% of oil and protein. The content of volatile matter and fixed carbon is nearly 80 wt.%, which indicates an excellent pyrolysis performance. Elemental analysis reveals that tobacco stem contains mainly carbon, oxygen, hydrogen, with a small proportion of nitrogen, potassium, calcium, magnesium and phosphorus. Compared with the lamina, the stem exhibits a more rigid structure, higher proportion of cell wall biopolymer, and less soluble materials.

From relevant research, tobacco stem has been reused for the recovery of nicotine and chlorogenic acid due to its high content. The biosorption of heavy metals is considered to be an alternative reutilization and presents a high binding efficiency. Additionally, by anaerobic digestion or composting, tobacco residues can be converted into biogas fuels like methane as well as fertilizer.

Pyrolytic Conversion of Tobacco Stem

Pyrolysis is a thermochemical decomposition of biomass into a range of useful products either in the total absence of oxidizing agents or in an oxygen-deficient condition. Tobacco stem has great potential to be used as a feedstock for this process due to its large quantity and easy availability. Once it is pyrolyzed into biogas, cleaner fuels would be available for rural areas as a supplement or even substitute of natural gas or traditional firewood. Research has shown that a slow heating rate, a high final temperature, and a long gas residence time will be necessary in consideration of maximizing gas production during pyrolysis. A caveat, however, is that tar will be unavoidably mingled in this process and, hence, a gas cleaning device is required downstream to prevent conglomeration.

The design of the pyrolyzer is crucial for a continuous reaction process. Unlike gasification, pyrolysis necessitates an external heating by microwave, or other heat resource like partial oxidation. Catalytic pyrolysis with additional carbon can effectively lower the pyrolysis temperature, producing more gas and less liquid, such as the pyrolysis under the condition of modified alkaline earth metal catalyst. Then, a condensation and purification procedure is introduced to remove the liquid products, particulates as well as unwanted components. Finally, the issue of gas storage should also be taken into account.

The resulting pyrolysis gas is made up of carbon dioxide (8–16 percent), carbon monoxide (25–37 percent), hydrogen (33–40 percent), methane (8–14 percent), and trace amounts of other light hydrocarbons (< 2 percent) for a gas-required pyrolysis, among which carbon dioxide and possibly existing organic compounds are of no use. Suggestions to increase the hydrogen content using specific reactions and catalysts have been proposed to reach almost 100-percent hydrogen yields. The product gas has a relatively high heating value of 13–15 mega joules per cubic meter, but the optimal operating condition is worthy of further study, including temperature, heating rate, residence time, and catalyst optimization.
In addition, tar can be physically removed or chemically decomposed with catalytical or thermal methods. As for carbon dioxide removal technologies, it is more economic in scrubbing, but membrane separation is expected as a potential option to improve removal efficiency in the future.\textsuperscript{22}

Applications have also been proposed for the solid and the liquid yields, namely biochar and bio-oil, respectively. Biochar is put forward to enhance its porosity contributing to a better liquid yields, namely biochar and bio-oil, respectively. Biochar has been widely tested to be utilized in engines, turbines, and boilers as liquid fuel, as well as in production of chemicals.\textsuperscript{27} Bio-oil has been proposed for the solid and the liquid components, as well as for an elevated organic matter content.\textsuperscript{26} Bio-oil can also be applied in soil management toward various undesired gas components, and potential applications of both biochar and bio-oil should be also studied.

The major challenges at present are to find a low-energy consumption and high conversion rate process related to a proper catalyst. For pyrolytic products, high removal efficiency toward various undesired gas components, and potential applications of both biochar and bio-oil should be also studied.

**Summary**

Each year, large quantities of tobacco stem are disposed of through cigarette production, of which a substantial part is discarded in landfills or directly combusted. Considering its high volatile matter and other polymers content, it is feasible to pyrolyze tobacco stem into gaseous fuels as a supplement to natural gas fuel through thermal or catalytical pyrolysis. Biochar through chemical activation to increase its adsorption performance as an adsorbent, not only as solid fuel, can reduce the overall cost. Now that sustainable development and renewable energy are drawing attention worldwide, bioenergy technologies are expected to find a way to drive economic growth, protect environment, and improve our life in the near future.\textsuperscript{em}

**References**