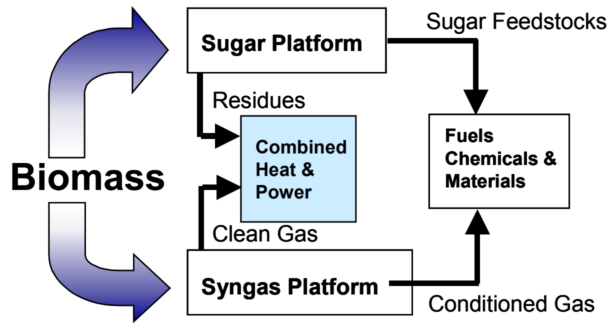
2.3.6 THERMOCHEMICAL CONVERSION OF BIOMASS

Technology Description



Biomass resources are agricultural crops and residues, wood residues, grasses, and trees. Biomass absorbs CO_2 as it grows, offsetting the CO_2 emissions from harvesting and processing, and can be a substitute for fossil resources in production of power, fuels, and chemicals. Biomass feedstocks currently supply about 3 quadrillion Btus (Quads) to the nation's energy supply based primarily on wood resources. The potential exists for increasing total biomass contribution to 10 Quads nationwide, which would create positive impacts on farming and forest products industries. Cost, sustainable supply availability, biomass variability, and delivery systems are key challenges for biomass utilization. Use of biomass resources as an alternative to fossil resources reduces most emissions, including emissions of greenhouse gases (GHGs). Through use of materials that would normally be waste, biomass systems bring about a net sink for GHG emissions, because methane emissions that would result from landfilling are avoided.

Thermal conversion of biomass is a manufacturing platform comprised of many technology routes and involves use of heat to break down biomass feed into an oil-rich vapor in pyrolysis and/or synthesis gas in gasification, which is used for generation of heat, power, liquid fuels, and chemicals. Technologies in this platform can provide the basis for a biorefinery, or be combined with other platform technologies. One advantage of thermal conversion processes is that they can convert nearly all biomass feedstocks into synthesis gas, including some feedstock components that are difficult to process by chemical or biological means.

The biorefinery is analogous to an oil refinery. Multiple feedstocks are thermally converted to a slate of products via multiple technology routes. Fuel production provides a large-volume product to achieve economies of scale, while lower volume biobased coproducts and power can improve the economic competitiveness of biomass as a sustainable source of energy. Integrated biorefinery systems are being evaluated for their feasibility in producing fuels and products for potentially large commercial markets. A major challenge is to develop the ability to convert the fractionated biomass components into value-added products as efficiently as the current petrochemical business of today.

Biomass combustion is a thermal process that converts biomass entirely to carbon dioxide and water vapor; and, thus, precludes conversion to intermediate fuels or chemicals. The existing biomass power industry primarily uses combustion to produce steam for heat and electricity generation. Co-combustion of biomass with coal, or "cofiring" has received recent interest as a way to reduce fossil carbon emissions from coal power plants. There are few significant technical barriers to increase use of these technologies.

System Concepts and Representative Technologies

Thermal conversion technology is important and has several key roles in an emerging bioeconomy:

- Most current biomass conversion is for heat and power generation and is based on direct combustion in small, biomass-only plants with relatively low electric efficiency of about 20%. Technology exists so that total system efficiencies can approach 90% if combined heat and power systems are applied. Most biomass direct combustion generation facilities use the basic Rankine steam cycle for electric power generation, which is made up of a steam boiler, an electric turbine, a condenser, and a pump. Evolution of combined cycles that integrate the use of gas and steam turbines can increase generation efficiency by up to two times. Cofiring of biomass with coal also can increase overall biomass-to-electricity conversion efficiency.
- A source of syngas for catalytic production of fuels, chemicals, and hydrogen is important. Once a clean synthesis gas is obtained, it is possible to access and leverage mature process technologies developed in the petroleum and chemicals industry for the production of a wide range of liquid fuels and chemicals.
- A source of heat and power for biorefinery operation. Virtually all other conversion processes – whether physical or biological – produce residue that cannot be directly converted to the primary product(s). In order to mitigate waste streams and to maximize the efficiency of the biorefinery, these residues can and

should be used for heat and power production. In existing biorefineries, residues are combusted in a steam boiler. There is a technological opportunity however, to use a gasifier coupled to a gas turbine combined cycle that can double conversion efficiency to electricity, while still producing steam from the gas turbine waste heat. Use of a biomass gasifier in a gasifier combined-cycle system can leverage on public and private investments in development of advanced- and next-generation gas turbine systems (more than $1 billion).

- Thermal conversion is a way to derive additional value from process residues. Within a biorefinery, thermal conversion and gasification can push many residues "up the value chain" through production of hydrogen or other higher-value products via thermal conversion to syngas followed by separation or synthesis steps.
- Gasification converts biomass to a syngas that can be substituted for natural gas in combustion turbines, shifted into hydrogen for fuel cell or other applications, or used in existing commercial catalytic processes for production of liquid fuels and chemicals. Several technologies exist in various stages of development for production of a suitable syngas, including indirect gasification, steam reforming of biomass, and gasification with oxygen or enriched air.
- Pyrolysis of biomass produces an oil-rich vapor that can be condensed for direct use as a fuel or as a hydrogen carrier, or refined for producing a variety of higher-value chemical products.

Technology Status/Applications

- The existing biopower sector, nearly 1,000 plants, is mainly comprised of direct combustion plants, with an additional small amount of cofiring (approximately 400 MW_e). Plant size averages 20 MW_e, and the biomass-to-electricity conversion efficiency is about 20%. Grid-connected electrical capacity was 9,700 MW_e in 2001; more than 75% of this power is generated in the forest products industry's combined heat and power applications for process heat. Combined utility and industrial generation in 2001 was more than 60 billion kilowatt-hours (about 75% of nonhydro renewable generation). Recent studies estimate that on a life-cycle basis, existing biopower plants represent a net carbon sink of 4 MMTC/yr. Biopower electricity prices generally range from 8¢–12¢/kWh.
- U.S. investment in equipment is $300-$500 M/year. At least six major engineering procurement and construction companies and several multinational boiler manufacturers are active.
- Biomass cofiring with coal ($50–$250/kW of biomass capacity) is the most near-term option for large-scale use of biomass for power-only electricity generation. Cofiring also reduces sulfur dioxide and nitrogen oxide emissions. In addition, when cofiring crop and forest product residues, GHG emissions are reduced by a greater percentage (e.g. 23% GHG emissions reduction with 15% cofiring).
- Small biopower and biodiesel systems have been used for many years in the developing world for electricity generation. OE is developing systems for village power applications for distributed generation that are more efficient, reliable, and clean for the developed world. These systems range in size from 3 kW to 5 MW, with field verification completed by the end of 2003.

Current Research, Development, and Demonstration

RD&D Goals

By 2005

- Resolve tar issues through integrated testing of candidate materials, catalysts, and technologies at appropriate scale.
- Verify hydrogen-production system and fuel cell operation.

By 2010

- Validate integration of gas treatment system with syngas-based biorefinery.
- Validate integration of hydrogen production or fuel cell operation with syngas-based biorefinery.
- Validate distributed fuels and chemicals production through industrial demonstration projects. Help the U.S. industry to introduce up to four new biobased chemical intermediate processing systems.By 2015
- Validate integrated syngas biorefineries through industrial demonstration projects.

RD&D Challenges

- Feed Preparation/Gasification – Improved feed processing for operational reliability need to be developed.
- Gas Cleanup – Improved methods of removing contaminants from syngas and modifying gas composition are needed.
- Synthesis gas utilization – The feasibility and optimization of syngas use in fuels, chemicals, and heat/power applications needs to be demonstrated on both a laboratory and industrial pilot scale.
- System Integration – Careful integration of the entire conversion system to maximize efficiency and reduce costs is needed.
- Development of enabling technologies is needed so that industry can reduce their risk of development and reduce development-cycle time.
- Verification and quantification of environmental and other benefits of themochemically derived fuels and chemicals is needed.

RD&D Activities

- Core research in feed preparation and handling, gasification, gas cleanup and conditioning, syngas utilization, and sensors and controls.
- Solicitation(s) for industry and university core research in targeted areas addressing specific barriers, e.g., high-pressure feeder development, novel gasification concepts, gas cleanup, hydrogen production, and sensors and controls.
- Solicitation(s) for precommercial validation of integrated processes for distributed fuels, chemicals, and hydrogen; and for integrated biorefinery applications.
- Joint DOE and USDA solicitations targeted to key enabling technologies can have an impact on meeting RD&D challenges.
- USDA has extensive research in crop production and is beginning to fund community-based, small-system demonstrations in collaboration with DOE.

Recent Progress

- R&D 100 award for the Burlington, Vermont, gasifier (Future Energy Resources Corporation, Battelle, and DOE Labs).
- Successfully demonstrated NO_x reductions from cofiring in excess of cofired percentage.
- Completed life-cycle assessments verifying and quantifying environmental benefits of biopower systems.
- Successful energy crop (switchgrass and willow) harvesting and cofiring in Iowa, Louisiana, and New York.
- Public release of modeling software (BIOCOST) that allows evaluation of energy crop production cost scenarios.

- Annual switchgrass yields of more than 10 t/acre obtained from best test plots in three southern states.
- Successful collaboration between private industry, DOE, and the USDA-Forest Service to demonstrate the small-scale modular production of heat and power in community settings (schools, small businesses).
- Demonstration at commercial prototype scales the use of biomass-derived resins from bark for engineered wood products.