Technology development benefits from stage gates at which the viability of the technology can be assessed before continuing with the scale up

Scaling up step by step

The recommended approach for scaling bioenergy and biofuels technology follows a similar stage gate process to that used in traditional Chemical Process Industry (CPI) processes. But the processing leads to some subtle differences, and unique challenges, that need to be considered.

Bench scale and lab scale systems are important early-stage tools for assessing and scaling new biofuels technology. Such systems are highly automated and customised for the application, and are a precursor to larger pilot and demonstration scale plants.

The most common operating configurations at the bench or lab scale are batch for continuous stirred tank reactor (CSTR), or autoclave, applications, and once-through for fixed or fluidised bed reactor applications. In batch autoclave applications, researchers typically load solids manually, close up the vessel, and run it at the desired temperature and pressure for a specific residence time.

In once-through fixed or fluidised bed reactor applications, feed and product is added and removed continuously. Researchers can then plot reaction yield and selectivity under a variety of operating conditions. Reactor volumes in bench and lab scale systems are typically less than 1000ml.

A frequent challenge for biofuels projects at the bench or lab scale is reliable solids feeding, which for some processes is required at high pressure. The solution involves prototype testing using a representative biomass sample.

In spite of these challenges, it could be argued that continuous pressurised solids feeding at the laboratory and pilot scale is more straightforward than at commercial scale where

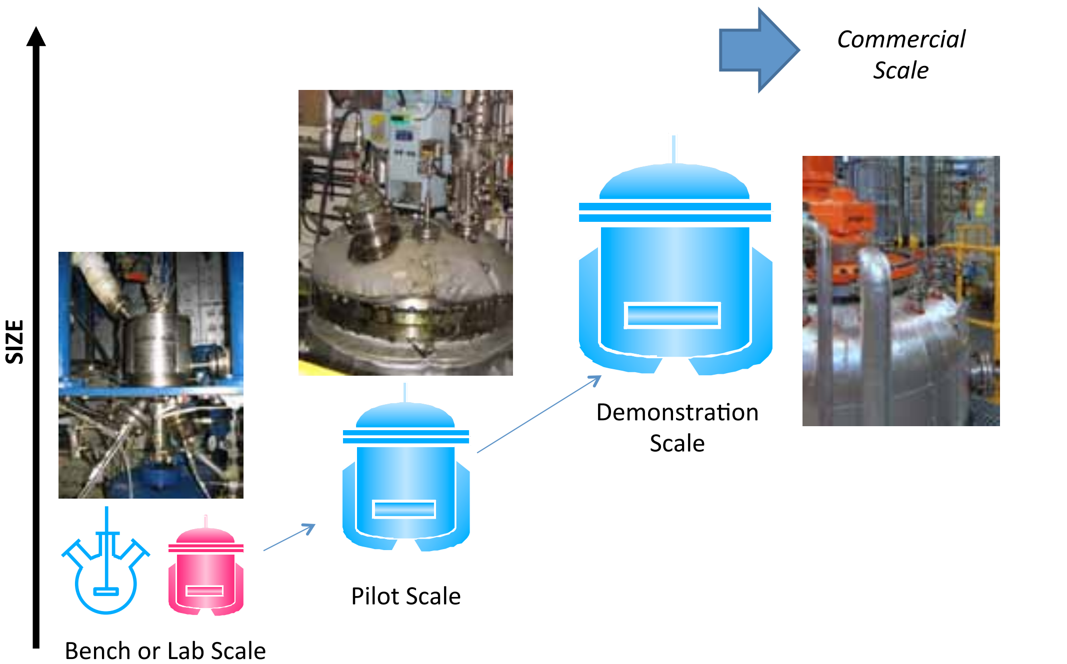
A novel lab scale ebullated bed reactor system for continuous bio-oil upgrading

much larger volumes must be managed, and where only limited technological solutions appear to exist.

Pilot plants provide the first window into continuous processing and often incorporate unreacted feed or product recycle. They are the workhorse of the process development world. Catalyst performance tests are carried out to determine, or confirm, yield and selectivity data, and the lifetime of the catalyst is measured under a variety of operating conditions.

For predominantly batch processes in which solids handling is not a major concern, scale-up from pilot scale directly to commercial scale may be possible. For continuous fixed or fluidised bed type processes, scale-up from pilot to demonstration scale is the norm. Reactor size at the pilot plant scale typically ranges from 1 and 100 litres.

Demonstration plants differ from pilot plants in that the equipment and process flowsheet much more closely resemble commercial scale operations. Extended operating runs permit catalyst lifetime studies over a longer period of time, while significant quantities of final product can be generated for market testing.



A visual representation of the technology stage gates commonly employed for process technology development

A custom-designed lab scale solids feeder capable of feeding biomass (wood) at a nominal feedrate of 100g/hr at pressures up to 700 psi

Scaling Factor *(typical capacity)*	Traditional CPI Gas-Liquid Process	Bioenergy Process with Solid Biomass Handling (dry basis)
Bench/Lab	0.001 - 0.1 *1 – 10 ml/min*	0.01 - 0.1 *1 – 10 g/hr*
Pilot	1 *1 – 5 l/hr*	1 *1 – 5 kg/hr*
Demonstration	100 – 1000 *5 – 100 bbl/day*	10 – 100 *1 – 5 t/hr*
Commercial	10000 – 30000 *30,000 – 100,000 bbl/d*	1000 – 5000 *200 – 1000+ t/d*

Typical scaling factors for bioenergy and biofuels projects alongside the scaling factors often used for more traditional CPI gas-liquid processes

The demonstration plant step is the final technology hurdle in the decision to go commercial.

Demonstration plants can have significantly higher capital and operating costs than a pilot plant, and are typically only employed when the process technology itself is already quite well developed. They are often installed at the future commercial plant site location to take advantage of existing infrastructure, utilities, operating permits and zoning provisions. Reactor volumes typically fall within the 100-1,000 litre range.

For continuous bioenergy and biofuels processes involving solids handling, the demonstration plant is an essential risk-mitigation step. Technology developers need to go to through the demonstration scale to prove to the market and investors that their technology meets its performance expectations, such as product yield and properties, and catalyst life, and is ready for commercialisation. The inherent risk in scaling continuous biofuels and bioenergy processes directly from lab or pilot data to commercial scale is, in most cases, too great to be given serious consideration.

Scaling factors

The scaling factor chosen for any particular process is highly specific to the technology under investigation, and management's level of comfort with the scale-up risk.

The typical scaling factors for bioenergy and biofuels processes are an order of magnitude lower, or more conservative, than is the case for an equivalent CPI process. This is as a direct result of the inherent challenges with biomass processing, and the fact that there is little published data, and a lack of experience in general, related to the scale-up of advanced bioenergy and biofuels processes.

Recommended approach

First and foremost, for companies actively engaged in developing biofuels or bioenergy technology, it is recommended that they systematically follow the stage gate approach outlined as they scale their process technology in order to minimise risk and maximise the likelihood of success.

In planning the timeframe to develop the technology through the pilot and demonstration stages, it is important to consider that the time required for start-up and commissioning of the plants will take longer than a traditional gas-liquid plant due mainly to the extra time required to fine tune the solids handling equipment.

Secondly, it is important that technology companies choose to work with partners and suppliers with real experience and a proven track record in the bioenergy and biofuels segment. Ideally, this experience should be drawn from the successful execution of bioenergy projects of similar scale and complexity, or else from projects in related industries like synfuels, heavy oil upgrading and coal gasification where similar challenges to those faced by the bioenergy or biofuels technology under

A pilot plant for a biomass catalytic cracking application


A demonstration plant in a cellulosic ethanol application

development have been overcome. This advice applies, in particular, to small, venture capital-funded start-ups, but also to multinational companies who are branching into more sustainable technology areas outside of their traditional industry.

For example, an engineering and construction company for a biofuels application should be able to provide scale-specific knowledge and experience in such areas as biofuels flowsheet development, safety engineering, value engineering, equipment recommendations, capital cost reduction and schedule acceleration. They should also have the ability to provide onsite support services following module delivery to facilitate a smooth and timely start-up of the plant.

Thirdly, how intellectual property (IP) is protected as the process is scaled up, and who owns the IP, are important questions that need to be answered by any company developing new and novel process technology, regardless of the industry sector. Any chosen partners or suppliers should have a complimentary position with respect to IP so that the issue of IP ownership is clearly understood by all parties.

Summary

As more and more biofuels and bioenergy pilot and demonstration plants come online, so the number and range of biomass technologies that reach commercialisation will increase. Assuming that the technology itself is sound, and the economics are justified, companies can maximise their likelihood of success by systematically following a series of well-defined stage gates during the scale-up of their bioenergy or biofuels technology.

Typically, the scaling factors used from lab through pilot and demonstration to commercial scale are lower for bioenergy plants than for traditional gas-liquid processes due to the solids handling requirements. Partnering with suppliers with a proven track record of success in similar applications will accelerate technology scale-up, while, with appropriate foresight, also protecting and strengthening the client company's IP position. ●

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