

# **Adaptable Biorefinery: Some Basic Economic Concepts to Guide Research Selection**

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## **ABSTRACT**

One important pathway to commercialize black liquor gasification for a noticeable impact on the US Industrial Energy Market is to operate at an adequate scale. Larson et al (2003) suggest a 7 CFA gas turbine operating from a 1900 dry T/day pulping operation. However, many ageing mills do not operate at that scale and most new mills have new Tomlinson boilers unlikely to retire in the next 15-20 years. If older, smaller mills face a rebuild, shut down or convert choice; it is arguably unlikely they will adopt the dual investments of a large scale gasification system and scale up pulping operations at the same time. One option for impact in the 25 year horizon is the biorefinery but the exemplar or reference mill arguably should address the realities of those mills likely to be conversion candidates in the intermediate term.

This work considers the adaptable integrated biorefinery that operates at a large scale for gasification but not perhaps at a large pulp making scale. This means that biorefinery conversions may look very different from place to place, producing different products, using different mixes of feed stocks and even producing different types of pulp.

Without determining the optimal product array here, the basic economic principles that drive these choices (and therefore the research priorities) are all familiar. Product Diversification and Market Influence wherein the producer or pulp industry collectively has some market influence beyond vulnerable price-taking positions and the value cycles among the various products are counter-cyclic, or obey a standard portfolio position.

Represented here are the basic micro-economic concepts that can be rewritten as a formal investment model. This way of treating the adaptable biorefinery may open new venues unexplored. Under favorable conditions that respond to the pulp mills as they are it may be possible to locate biorefinery conversions where initial outlays remain more modest, new value streams may be drawn from agriculture as well as from forestry, and pulp mill adaptations may be a platform able to add new products (extracted chemicals, fuels, hydrogen cells) as they come on line rather than depend on these breakthroughs to commence commercialization. Technical hurdles exist, but are perhaps less constraining than other technical hurdles to commercialization in the shorter time horizon.

## **INTRODUCTION**

The conversion of existing pulp mills into biorefineries emerges naturally out of the high energy potentials in many of the waste streams in pulp and paper making. In addition there is often rare chemistry from processed or pre-processed elements that can be used in commercial products. Of the biorefinery products considered, by far the most extensively examined is syngas transformed from black liquor. Black liquor gasification, especially coupled with a combined cycle turbine (BLGCC) is likely to be a component of successful conversions of pulp mills into multi-product biorefineries.

This work considers market principles and strategies that affect a successful conversion of US pulp mills into multi-product biorefineries. The premise is that the baseline physical plant differences from mill to mill alongside differences in local resource supply and goods demand dictate that the most profitable portfolio of goods to produce at a given biorefinery conversion will be far from uniform. As we direct biorefinery research interests, we may need to be sensitive to local adaptations and resist developing a singular biorefinery reference model that is not fully adaptable in construction to respond to local realities.

Biorefinery realities may suggest highly differentiated pulp mill conversions to realize meaningful market penetration into key product markets and to be responsive to the initial capital base of the mill, local natural resource availability and accessible product demand if the industry aspires to transform a reasonable number of mills. This lesson can be understood in the context of BLGCC reference mill research.

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A recent DOE report by Larson et al (2003) suggests that the implementation of a combined cycle black liquor gasification operation is a first step toward a biorefinery. They show in a reference mill case that this technology is nearly commercially viable today. While not quite a biorefinery, the converted kraft pulp mill retro-fitted to produce syngas for electricity as well as pulp is modeled to feed syngas from black liquor into an on site gas turbine up to 7 CFA in scale.

The DOE study targets a reference mill that produces 1900 short dry tons of paper per day. It is assumed that the majority of mills at this size have a Tomlinson boiler expected to expire in the next 10-20 years. Their reference mill pulp output is not arbitrary. This production scale is a level widely considered necessary to remain competitive in a stand alone pulping operation. So the Larson et al study becomes a critical reference for research; yet it may not be a ready blueprint reference for conversion.

First not many operating pulp mills produce at the 1900 tons per day scale. It is these mills that are likely to shut-down in the next ten year years. Second, on inspection, those now operating at the competitive scale already have *relatively* newer boilers retiring well beyond the assumed planning horizon. Third, in general, the 30-40 year assumed life of a boiler may not be realistic. Advances in the late 1990s when mills fell under severe economic pressure induced innovations that greatly extended the functional boiler life at many well-run mills. Arguably, such innovative local management and staff are premier candidates to orchestrate a successful conversion.

Conversion to BLGCC then faces a dual obstacle: many of the best candidates for conversion are not large enough to support the gasifier / turbine capital combination at the economic scale examined and those large enough to convert are not ready for conversion in the intermediate term.

The DOE report however is still extremely important as an engineering economics feasibility baseline around which both gasification and the biorefinery research can pivot. New value streams beyond syngas production open the possibility that the economics may be more forgiving; allow more mills to convert their operations from a smaller pulp-making scale.

Smaller operations may find a blended product conversion that includes gasification and other high value added products attractive just as larger operations may have enough biomass and process residuals on hand to generate new chemical products, such as high valued polymers, to justify direct gasification of these by-products even if, for the time being, they fail to gasify black liquor. For small mill conversion, I argue, blended co-firing of black liquor and other biomass products (including biorefinery product residuals) may be critical to reach the appropriate scale for a gasifier/turbine capital combination. For large operations, they may produce syngas from non black liquor elements for the moment and successfully side-step the technical obstacle to gasify and co-fire a soluble with a non-soluble element.

In the near and intermediate term, conversion of well-run, medium scale pulp mills may necessitate the additional product mix output flexibility promised by a biorefinery. For purposes of this work, I consider conversion to a biorefinery to include some measure of gasification at the mill. Black liquor gasification may completely replace a Tomlinson Boiler or boost output incrementally to take advantage of a mill's excess lime-cycle capacity, a common condition throughout the US pulp industry. With appropriate advances in co-firing, the waste streams of other biorefinery products might be co-fired with black liquor to justify a larger scale of the gasifier. Co-firing may be necessary in the baseline Larson reference case as well since a shortage of steam in the final energy balance may not always justify importation of additional trees solely for this marginal need.

Biorefinery conversions in particular may be highly individualized – carefully tailored to each specific mill. As the research agenda for biorefineries forms, it is important that all reasonable products, probably via a mill by mill inventory, be arrayed to account for this need to adapt. This implies more than a single reference plant as a research goal. Below is a very short record of basic economic principles of optimal portfolio choice and market penetration as a method of market research that may dictate different products to target in biorefinery research.

## PRODUCT PORTFOLIO CHOICE

The key economic advantage that US pulp mills enjoy is often over-looked or under-stated. An ineradicable economic obstacle to biomass gasification has long been to transport the biomass in a cost efficient fashion to a processing center.<sup>†</sup> Pulp mills already deliver high valued biomass to an operating center to make pulp. That gives the mill an exceptional economic advantage to expand its product lines in this direction. Syngas production may ease the capital return burden levied exclusively today on pulping to leverage current capital to generate electricity.

Yet the size of capital investment and the proper mix of assets to install escalate certain risks. Potentials for stranded investments are high. Operations to make pulp, produce syngas, export energy via large gas turbines, refine methanol, DMEs or Fischer- Tropsch fuels and extract specific polymers (and many other product now on the table) suggests a very heavy price tag. If the capital is product specific, as is most pulp-making machinery, these products either return a profit or the plant closes. Any flexibility to move between products as conditions change or at least to adapt an operation to particular constraints and opportunities is highly valued.

Securing a return on capital sufficient to manage risk, especially in the very first years of operation, is the *sine non qua* for the vision to convert US pulp mills (any US pulp mills) into a biorefinery. It is trivial to note that the key to risk reduction is diversification. New product streams offer the promise of adding to expected profits by simply extracting more commercial products from the same capital base but joint production or less restrictive “menu production”<sup>‡</sup> also permit diversification; but as any investor knows this logically means the goods need to be counter-cyclic in prices (and profits) as a risk hedge. In simplest terms, Figure 1 provides a graphic of this well known phenomenon represented as random shifts in demands for the goods produced.<sup>§</sup>

Given the high returns on capital (IRR) that prevails across the industry (unpublished: Farmer and Siquefield, 2004), the industry is far from risk-neutral in its approach to capital investment.

Figure 1 represents two elements in the biorefinery portfolio where strong demand in one product appears at a time when we expect low demand in another product. For reasons clear in a moment, the markets are emerging and full capacity to satisfy demands at least initially has not been met. This means there exists for the US pulp industry some modest market positioning of biorefinery products to generate a surplus (i.e. producer surplus).

As *Biorefinery Product A* experiences a downturn, *surplus* returned to the firm *drops* by the hatched (green) area. Remaining surplus is in solid (red). Yet *Biorefinery Product B* generates a surplus return to capital that *increases* by the green hatched area *from* the area in red. If, overall, the total surplus is expected to be relatively stable, risk of course is mitigated considerably among these relatively volatile market products. Paper prices have tended to move over a relatively large price band, and energy prices, a major biorefinery export, tends to display volatility as well.

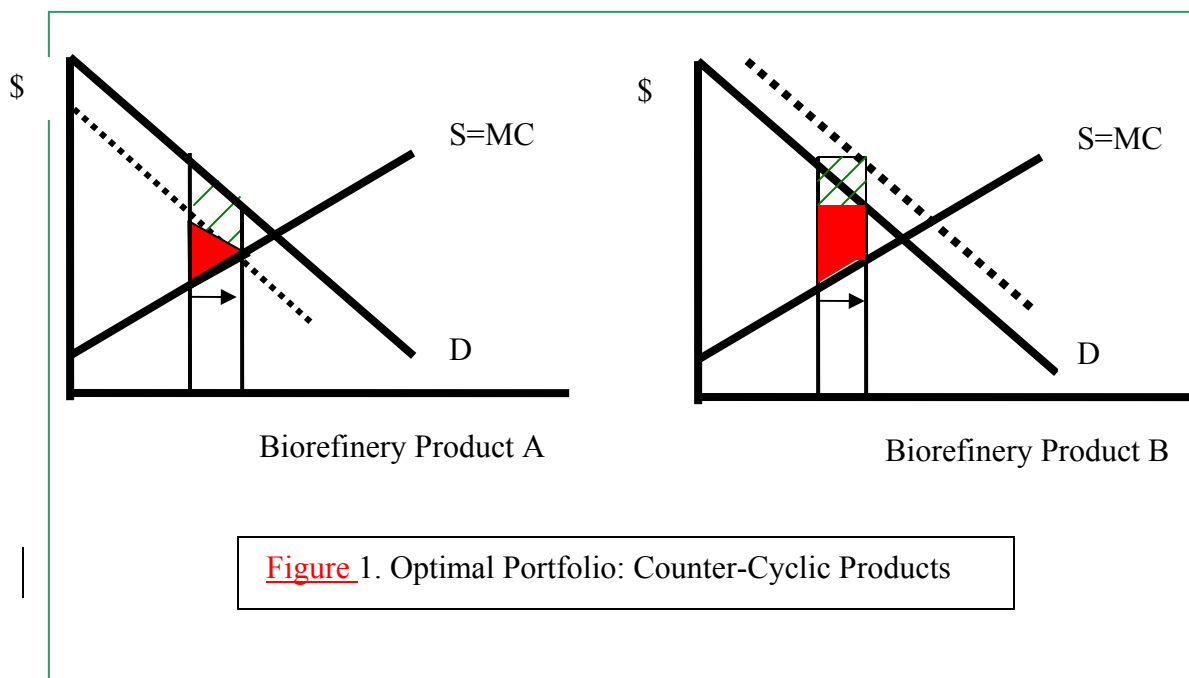
To merely introduce an example of this way of thinking, consider a possible counter-cyclic product previously overlooked. Agricultural goods and their field wastes might supplement biomass to help assure an efficient scale for a gasifier and a gas turbine if energy prices reduce forest harvest and deliveries imported not for pulp but only to supplement syngas output to cover steam deficiencies. Agricultural inputs can be highly pro-cyclic or counter-cyclic to energy prices depending greatly on local conditions. Rye producers (a very large field product preceding cotton in double-cropping systems across the lower southeast) tend to forgo tasseling in the last month as it is very fertilizer intensive. Cotton itself receives a fertilizer boost from stemmed residues to benefit the farmer but not so much to risk root fungi. If technology allows, the rye bales within a small radius of pulp mills (common especially in South Georgia where larger mills are located) can be sold to supplement high valued energy production through a gasifier/turbine capital unit.

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<sup>†</sup> Variants to build bigger gasifiers to bring down unit costs to overcome transportation costs or to produce small gasifiers to go to the biomass are really economic extensions of this same problem.

<sup>‡</sup> Joint production traditionally means two products are produced out of the same operation that very little marginal cost is required to generate the second good. Menu production allows more choice to turn on and turn off certain product streams as conditions change.

<sup>§</sup> Cyclic shifts in input prices (or production costs) can be incorporated without loss of generality.



Many other polymers are counter-cyclic to energy while others are pro-cyclic, naturally favoring counter-cyclic goods. Similarly, some bio-oils with less exacting production standards than DMEs or Fischer-Tropsch have spot markets that may favor this product for some *minority* of mills. Slow release fertilizers are in high demand in the marshier areas in the lower southeast, helping farmers apply fertilizers in the wet early spring with more precision – getting in once when conditions favor and apply a lot or as little as forward market conditions to harvest (or their hedge prices) demand.

Within this zone is Florida where importation of electricity via electric grid access operates in a startling narrow window. Pipeline sales of syngas north of grid transformers and direct sales of electricity south of that bottle-neck can favor direct syngas production with any bio-oils directed to serve the special needs of the local farmers. This is counter-cyclic at some level. When energy prices are high, fertilizer demand wanes yet syngas sales soar and visa-versa. Further, various resin protectors and deck wood preservatives producible at a biorefinery with the equipment being suggested increase in demand as alternative markets for timber increase pulpwood prices – a clear counter-cyclic risk protection. These examples are not recommendations and deliberately fetched; yet they exemplify the types of market research needed to assist bio-refinery research and the potential for quite local conditions to dictate product choices.

### MARKET PENETRATION PRINCIPLES

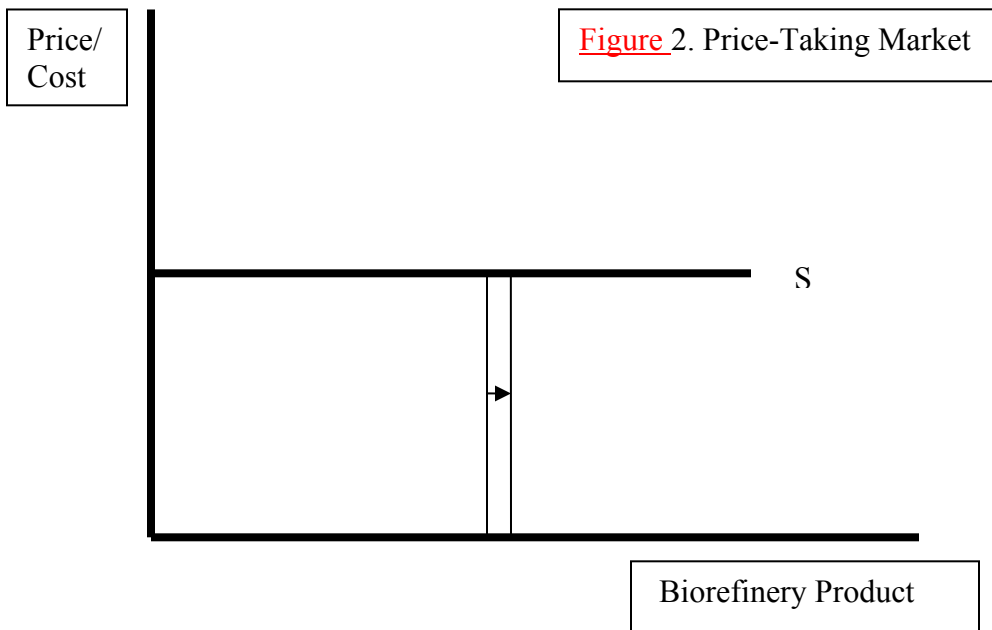
One possible concern for the biorefinery is that its entry might affect markets and drive certain local resource allocations, pitting energy production against pulp production and forestry or influencing prices. Yet arguably after decades of brutal market volatility with the industry vulnerable as price-takers in pulp and paper markets, influence over local demands and prices suggests new sub-markets to enter to realize incredible new profits. Like any powerful, well-balanced portfolio, even periods of very high returns suggest moderated profits or even losses for some elements in the basket of investment (i.e. output) choices.

Again in an appeal to fundamentals, volatility can be tolerated if the risk is well hedged and/or if the returns are sufficiently high.

Here I argue to delineate the array product choices for a biorefinery there appears many such unexamined market penetration effects as biorefinery research priorities cement. Absent an inventory of mills, their on site capital and capacity, age of existing equipment, scale of operation dovetails into an examination of local resources (is there coal nearby?) and markets (do DMEs or Fisher-Tropsch command a higher local price down the road), a proper expansion of the product set cannot really proceed.

Below is simply an intermediate micro-economics comparison of two types of markets mills might enter as they introduce biorefinery products. Figure 2 is a familiar competitive market in which the contribution of the particular producer of interest (e.g. converted pulp mills) deliver products at market prices, which their own additions to supply cannot affect.

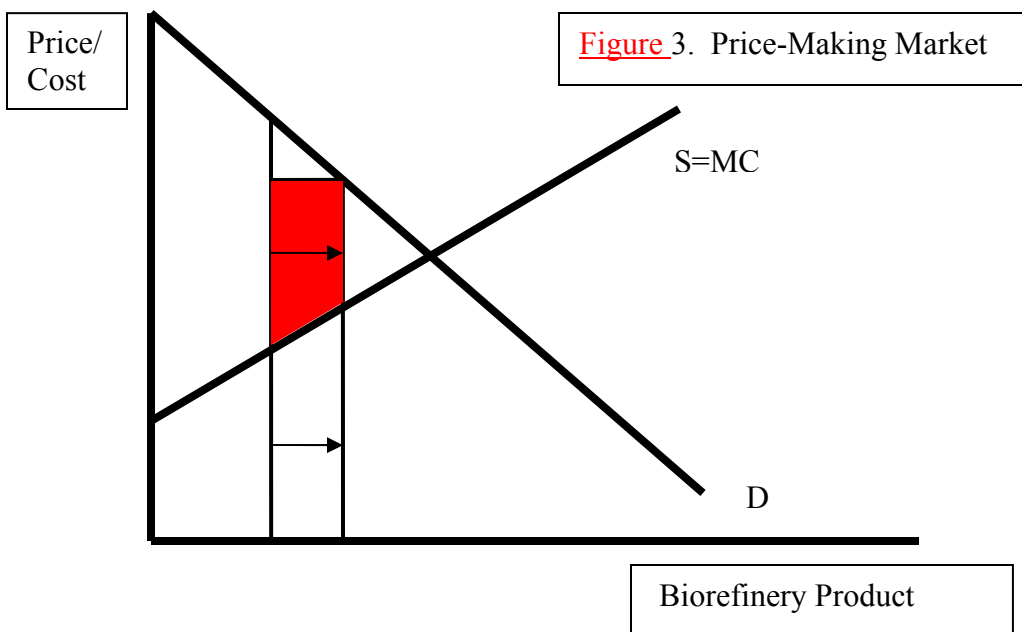
Given an industry with high capital costs, to find one in such a market is a highly unenviable position for a producer. In almost every way, this market condition characterizes today's pulp and paper industry market structure from forests to pulp paper to most forms of final paper products. This single vulnerability is, in part, a strong statement of the industry's challenge: Indeed, in some ways this price-taking vulnerability is the very reason to attempt to strike out into new product lines that complement pulping operations already installed.



Economically, price-takers have an either/or choice to enter the market or forgo its production. The taken prices that the producer must accept need to generate sufficient return on capital. So, to add-on new capital, the scale of operation alone has to justify that capital investment.

Certain energy markets for biorefinery products have this characteristic. Prices may be high and even accelerate to justify entry and make the capital investment. Yet many of these same markets are also volatile historically.

While unit costs of these new energy products may be low due to complementary production of pulp and energy products that can reduce per unit costs, the margin of cost over price still may not compete with much larger scale operations specialized in a particular refining process. If the biorefinery-converted pulp and paper industry is a small player in these markets, biorefinery returns will be highly vulnerable to improvements in refining, made by those who specialize in refining. Absent some entry and exit capability with the capital installed the shift among different products in which the biorefiner is always a price-taker or some direct market control for some products, even exceptional innovation and stellar technical process management can be erased.



Conversely, an emerging market with few entrants market-wide, or few potential competitors locally, may be impacted by the entry into this market by a biorefiner who operates through an expanded / converted pulp mill. Here the increased production into the market is not monopolistic but includes few enough producers so that the biorefiner can extract rents to augment production, providing some cushion to secure returns. The area in red represents sales of the biorefiner to a given market where prices, at least in the first years, exceed supply costs.

Concerns for Price-Fixing can arise to check this, but there is reason to be optimistic here. If the entry into the market adds competition, the prior level of price manipulation is reduced – a public benefit. Also if the product is an emerging technology developed with foresight by the industry collectively and makes good use to leverage government research dollars, such surplus is generally considered a reward for innovation akin to patenting, yet without the more intrusive disruption that patenting introduces.\*\*

Even for large products markets this may shift from region to region. DMEs at the moment require engines specially designed for DME fuels alone while Fischer-Tropsch is a synthetic diesel perfectly substitutable for diesel. In some markets that may make DME production highly vulnerable to demand interruptions. At other locations, paucity of local sources provides at least some local market power during high energy price periods where a stable DME fleet exists.

On the other hand, industry will have to be convinced that Fischer-Tropsch production is a reliable, flawless substitute for refined diesel – why this is a possible biorefinery research priority. Yet if synthetic diesel makes a very small contribution to total market supply and mills sell Fischer-Tropsch fuels to a diesel ‘wholesaler’ (i.e. oil company) and not a final user, the dual prospect to lose the full advantage of a high price spike is married to the risk of demand interruption during downturns. Yet these are valued products. The lesson is that for the same biorefinery product mix, some mills that are positioned better geographically and others are positioned better to operate at a more effective scale. One size unlikely fits all – or most.

\*\* If the industry initiates a biorefinery program coupled with public dollars and then individual companies add-on (some say free-ride) innovations that litter the biorefinery with patents, not only will entry be expensive but public policy may easily view the initial research support adequate with patenting available as a reward to take care of everything from there. This is merely a warning that collective research collaboration on biorefinery products may be more important than previous initiatives and uncooperative patenting fever could undo the entire experiment.

Again, locating high value-added products in emerging markets that promise stronger revenues during the early, riskiest years of biorefinery conversion, is critical. Some simple products that may be in high demand in the short-run include: chromated copper arsenate (CCA), a wood preservative to substitute for banned arsenic-treated wood; polylactic acid (PLA), a high value biodegradable polymer with unique physical and chemical properties or, on the pulp process side, extracting H<sub>2</sub> from the syngas to produce peroxide for elementally chlorine-free (ECF) bleaching that may have high short-run returns while installing the long-term use capital to contribute to hydrogen fuel cells, should that technology ever evolve. These products are only examples of the concept.

The lesson is rather simple. It is inadequate to define research priorities on a single reference biorefinery operation if that reference model is premised on three perceived objectives for optimality:

- 1] High expected price for each new product stream is the sole economic value criteria rather than overall portfolio mixes among products;
- 2] Marginal market control for a product (at least for some period) is not examined technically in a market assessment as a value criterion;
- 3] One model of the biorefinery is presented whose technical co-integration parameters are too narrow to permit reasonable adaptation over space (by region), over scale (by installed capital) and over time (by product mix).

Fortunately for the economic analyst, future price expectations product-by-product are much more difficult than the cross-price elasticity measures necessary to examine product inter-relationships and the presence of modest market power.

## **PUBLIC POLICY COORDINATION**

Most models of the converted BLGCC or more exciting biorefinery ambitions rely, at least initially, on some public-private coordination. The most familiar are Green Energy Credits, favorable environmental regulatory relief and credit assistance (e.g. low interest loans and guarantees). Efficiency is on the side of the industry as these clean, green, job-saving, energy independence benefits are valued by society – some as fairness objectives (jobs, energy independence) and some as real economic goods providing real benefits (environmental services).

The economic point here is not mere rhetorical linguistics. Unlike farm subsidies that now support a favored group at the expense of the economy, the reasons a potential biorefiner requests assistance is that she produces a good that adds to the economy, grows the economy and delivers a real valued product that passes a full economy-wide benefit-cost test: total willingness to pay to receive the product exceeds the willingness to accept compensation to produce it. These goods improve efficiency and national economic progress so to label these economic products as ‘social or societal impacts’ is a great disservice. That language eradicates the very clean economic distinction between an economic good and a transfer payment. The reverse is true. To produce an uncompensated economic good is a transfer from the biorefiner to society. If lack of compensation leads the biorefiner to under-produce the good there is a strong social benefit to achieve that *economically efficient* level of output.

With such a strong hand, it is also true that the public wants a large return on its partnership dollars. Just because an environmental improvement is worth billions of dollars in terms of real economic value if the service could be sold in a market does not mean that public entities will pay up to value even though it can be economically efficient to do so (i.e. raises net GNP). Public bargain hunting means that industry will have to position the biorefinery initiative to assure these public services at relatively modest cost on the dollar benefit. Again product choice, portfolio mix and market position will influence the costs of public outlays.

Consider then the last two figures as extreme poles of public/private policy-partnership.

**Case 1:** No Counter-cyclic Goods in the biorefinery portfolio and all price-taking goods.

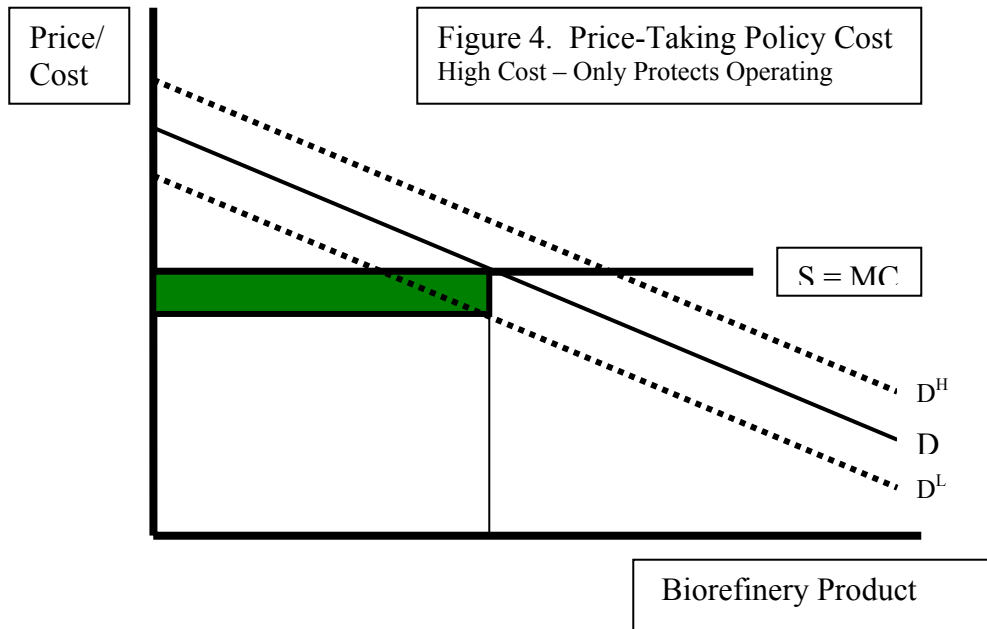


Figure 4 records a standard commodity program with a strike price that protects producers by establishing a price floor. If Demand,  $D$ , is expected demand that sometimes rises,  $D^H$ , and sometime falls,  $D^L$ , policy-makers may protect basic operating costs against strong losses by directly compensating producers to the just basic level of returns to protect against shut-downs or subsequent supply disruptions. Green energy credits are really a permanent or on-going form of the price floor. The cost to the public is the area in green, measured in currency, perhaps only inaugurated when prices fall temporarily. Green credits assume that even normal conditions may fall below the level to induce investors.

The compensation is often large and, policy makers have finally learned, loan guarantees are functionally equivalent to a price-floor policy; so the policy here applies with out loss of generality to that program as well.<sup>††</sup> The entire guarantee project *may* be economically efficient if the market demand fails to account for a so-called ‘positive externality’ of production and the public benefits at large from securing these external benefits.

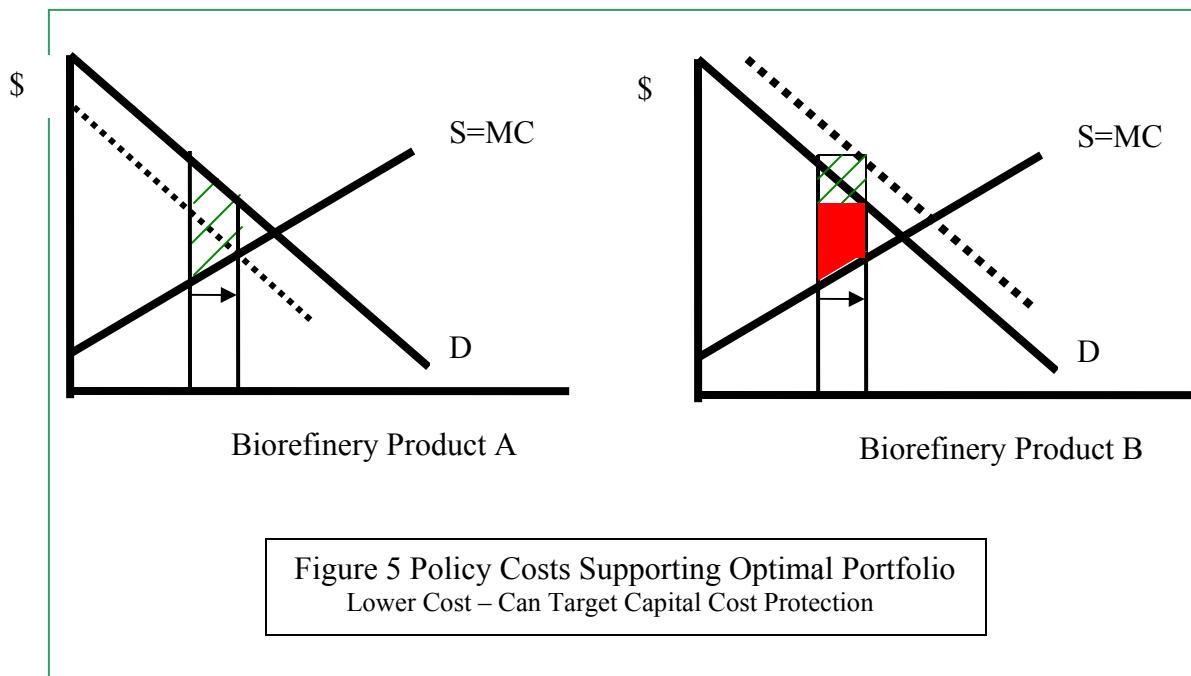
Yet the program applied to agriculture has been expensive historically. Given the experience of farm programs, whether they translate to this circumstance or not, this arguably impacts the mind-set of policy-makers. It is the growing expense of these programs that has led most states to slowly retract their Green energy credit programs. Benefit-cost models of a biorefinery option need to be alert to the policy uncertainties surrounding by volume green energy credits as represented on Figure 4 above.

**Case Two:** Risk- Balanced Product Portfolio and Product Market Position.

Another option is to establish a public-private partnership on less dependency terms with the government authorities. If the biorefiner has positioned her product array to minimize risk with counter-cyclic products and has judiciously entered emerging goods markets (which are usually higher tech), support of the enterprise as a whole system provides the policy maker with considerable latitude.

<sup>††</sup> A loan guarantee or a partial loan guarantee (say covers first 5% of loan loss) is simply a profitability strike-trigger. Each can be structured in different ways to affect incentives of producers but for every strike price, price-floor policy there exists an equivalent loan guarantee program.





For example, if some of the biorefinery products include bio-oils from on-site pyrolysis of biomass, even if limited to woody biomass, the producer may be able to shift somewhat among these products as profitability conditions change. Policy-makers may see the advantage to encourage the marginal adjustment process by modest direct subsidy only to speed up the implementation process. Likewise, the policy-maker may value the original product mix and may desire to induce the producer to remain with a product that produces high external benefits. The costs of these interventions and inducements are arguably much cheaper.

Also there may be ‘perfect storm’ threats that temporarily erode demand in these new higher tech products and force counter-cyclic goods to move for a period in concert. Strike price interventions then are not promises that establish a price floor, but give the policy-maker options to inject incentives on well-established rules for exceptional market risk. These protections for industries producing policy-favorable goods are widely used and can come in many forms. Generous tax exemptions can be delayed until conditions return so as to reward the producer to ride out the storm; market interventions can address directly the unexpected conditions if they are from external shocks or, frequently, is clear excessive market manipulation occurs.

Finally in a ‘perfect storm’, direct partial interest payment on borrowed funds for a short period or product price supports as above are also possible; but the terms are potentially quite different. Expensive, on-going price supports and regular strike price guarantees (including green energy credits) have the tendency to support sustained operation only and cover prices enough to forestall shut-down conditions. Given their regularity and large outlays when triggered, this is likely even if the product claims to increase economic productivity (more efficient) rather than function as a transfer payment.

Interventions to protect a well-positioned industry that embeds considerable flexibility and adaptability can be less frequent. In these better positioned and less risky operations, capital intensity means that subsidies are almost useless unless they protect long-term capital viability: protecting profits rather than preventing minimalist shut-down conditions. An industry that can make that case while adding to the national economy, creating newer higher tech products and preserving rural jobs at a higher technical level and increasing energy self-sufficiency is in a good position to establish policy supports for unexpected hard times on more favorable and even terms.

Finally, the commitment to holistic preservation of the entire biorefinery operation – as a system – rather than product by product support has the potential to lift the industry out of piecemeal regulation. Growth and maturity of Project XCEL at EPA has been able to operate favorably with other high environmental risk agencies over the last six years.

## CONCLUSION

Overall the biorefinery concept has the potential to transform the industry while meeting traditional product services. Yet it is also important to recognize the time-table for the US industry. Existing infrastructure and the timing of its retirement suggests that the selection of a biorefinery research proposal pass a market viability test. Part of this is to conduct a benefit-cost test on an anchor base case model; but beyond that business decisions usually demand more. A full market review and strategy for research priorities with a realistic implementation plan, perhaps even mill by mill visioning, would be a standard request for an initiative of such ambition with width of application. Probably the easiest way to apprehend the important differences between the two analytic approaches is that a benefit-cost model uses given prices and couples it with sensitivity analysis while a marketing plan 'model' at some level of formality the structure and the evolution of the structure that explains prices.

Provided here are a few basics on how to think about that marketing plan and feasibility of implementation, at least at the rough but arguably reasonable outline levels. The principles of portfolio analysis and market penetration are rather straightforward in themselves but the devil is in the details. Engineers may appreciate an analogous difference between writing down the principles of Newtonian physics and launching a space shuttle. Of the basic principles one general research area emerges from a review by a non-scientist: for gasification to realize its appropriate operating scale the possibility of co-firing alongside black liquor would be a tremendous advantage that adds enormous flexibility if it can be achieved. Small mills may be able to adopt gasification and export electricity without scaling up if local herbaceous, woody biomass or other carbon rich products (coal) are available locally. Co-firing might enable certain products with energy rich waste streams to be produced on site (high value polymers or products prior to pulping) while contributing to the energy needs to produce the good.

Again my point is not a technical one to advocate a singular technology but to illustrate the principle for divining a research agenda and meeting the needs of the pulp-making infrastructure in place today. The enormous talent and imagination gathering in commitment to this nascent research initiative is impressive. This work stands as a reminder to garner that work to its greatest affect.

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