White Paper

Ethanol vs CO_2: Analyzing Capital Costs Relative to Throughput

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About the Author

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An entrepreneur with extensive experience in every facet of the cannabis industry, Adam has invested his own capital and played a key role in launching two industry leading cannabis ventures since 2014, and has personally developed proprietary extraction processes and equipment, cannabis growing systems, market leading extract delivery systems.

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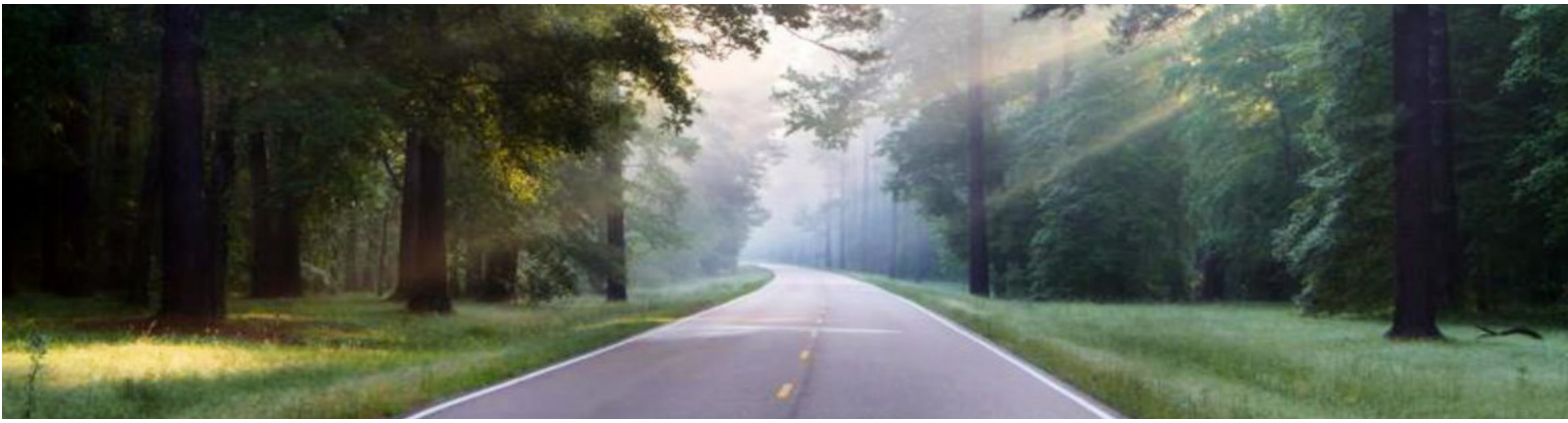

“If you don’t know where you’re going, any road will get you there.”

Any Road*, by George Harrison*

INTRODUCTION

For cannabis plant oil processors seeking a prime position in the infused product marketplace, sorting through equipment options and methods for performing extractions can overwhelm and confuse the decision-making process.

“*Because that’s how everyone’s doing it*” is a common response from those who are asked why they’ve chosen to investigate or purchase a particular extraction solution or system. But what’s best for one business or product line is often not best for another.

Sheep mentality, media hype and the presumed wisdom of crowds can influence the purchase of extraction technologies more than business planning, dedicated research, or objective comparison of the options available.

This white paper endeavours to be a resource for businesses seeking to evaluate the relative benefits of the two dominant extraction methods under consideration by many players in the cannabis industry — ethanol and CO_2 — on the basis of an analysis of capital costs relative to plant material throughput.

THE BUSINESS PROBLEM

The core problem for many businesses in this sector comes in the form of a question: “*What’s the best extraction method — CO_2, ethanol, hydrocarbon, or something else?*”

There’s no correct answer, because the question is based on a faulty premise — that a best extraction method could be definitively stated for any circumstance. Without laying out the proper context in which production is being considered, no single extraction method is better than another, and any business performing extraction, or looking start, should be wary of any such claims.

Instead, the better question to ask might be: "*What's the best extraction method, based on my desired end product, throughput goals, and budget*?"

Generally, a combination of different methods comprises the ideal process for any given product or ingredient being produced. There's no 'silver bullet'; choosing the right extraction process, and thus the right equipment, is dependent on your company's business model, and must be designed based on your needs.

RE-STATING THE QUESTION

The decisions being made at start-up or during business expansion can significantly impact the cost of production and market competitiveness, often in ways that are difficult to reverse.

Before making such investments, businesses should consider their end product goals. Answering these questions will reveal the respective advantages and disadvantages of the different concentrate manufacturing processes, particularly between CO_2 and ethanol:

1. **What is the intended end product or ingredient from the extraction process?**
2. **What is the grade and terpene content of the plant material being processed?**

With the right planning mindset involving the right people, any organization can determine the extraction processes that are right for the business model.

MANY MANUFACTURING MODELS

Cannabis processing is a manufacturing business. There are countless potential end products, each requiring its own best case production process.

The manufacturing process for any two cannabis products could be as fundamentally different as the processes for manufacturing windows for homes compared to manufacturing carbonated beverages. While there would be some similarities in planning, procurement, or inventory management, each will have a highly specialized production line, designed to produce that unique end product.

The same principle applies to cannabis products. To design an optimal extraction process, we must first define the end result we are pursuing. Once that has been established, comparing extraction methods is straight-forward.

The two main cannabis extract business models are consumer products and the active ingredients those end products require. In either model, as many at 15 processes could be involved when transforming raw cannabis material into an end consumer product; oil extraction is only the first in a series of steps.

Businesses need to decide whether they will produce products for end users, such as edibles, beverages, topicals, vaporizers, or dabs, or ingredients to infuse consumer products, such as distillates, isolates, full spectrum oils, high terpene extracts, and crude oil, to name just a few.

Once a business has defined its end product, target production volumes, and a budget for capital and operating costs, four main considerations must be taken into account to determine the ideal extraction method.

CONSIDERATION #1: POST-EXTRACTION REFINEMENT

The requirement for **winterization** is one of the most important factors to consider when choosing between ethanol or CO_2 extraction.

Performing a full-spectrum extraction with a CO_2-based system — which results in extraction of both terpenes and cannabinoids together —and then winterizing the resultant crude oil is a lot like hand-washing your dishes after a meal, and then putting the dishes in the dishwasher. Your dishwasher is much more efficient at washing dishes than you are with your hands, in addition to the main issue of inefficiency — washing the dishes twice was not a very good use of your resources, because they would have come out of the dishwasher perfectly clean and dry anyways.

This is similar to the extraction processes being used by many cannabis business today. The CO_2 extraction process picks up a lot of waxes and lipids, requiring the crude oil to be dissolved in ethanol for winterization.

In this scenario, CO_2 extraction is unnecessary; had ethanol been used as the primary solvent, the result would be exactly the same: winterized oil, dissolved in ethanol, ready for evaporation.

This is a particularly expensive mistake, as the throughput of CO_2 extractors is substantially limited by the engineering required to achieve supercritical pressures. Commonly, six or more CO_2 extractors are required to achieve the same throughput as one ethanol system in the same price range, though the multiplier varies when comparing different systems.

If your products require a winterized oil then choose ethanol for your extraction process. However, starting material is also a consideration. Consider chlorophyll — CO_2 is much better at leaving this compound behind, whereas ethanol has a propensity to extract such water-soluble compounds, especially when below 190 proof. Processors using alcohol as the only solvent to make winterized oil should consider passing their oil and ethanol solution through a media filter to remove chlorophyll if the grade of starting material is low.

Some end products, such as tinctures, edibles, capsules, topicals, only require **crude oil** instead of winterized oil. Anything that's not going to be vaporized could use crude oil as the active ingredient. (See *Table 1: Cannabis Extraction Ingredients & End Products*.)

	INGREDIENTS	STARTING MATERIAL	END PRODUCT
Winterized Oil Any grade of oil with waxes removed to prevent solidification.	• Distillate • Isolate • Full-spectrum oil	• Trim • Hemp • Outdoor grown cannabis • Small flowers • Top flowers	• Vape products • Dab products • Edibles • Tinctures • Beverages
Crude Oil Unprocessed, unrefined oil extracted from organic material.	• Crude oil	• Low-grade trimmings	• Capsules • Topicals • Suppositories
High Terpene Extracts Naturally balanced cannabinoid and terpene concentrate, extracted using low boiling point solvents at sub-zero temperatures.	• High terpene extract (aka Terps Sauce)	• High terpene content • Indoor flower • Outdoor flower	• Vape products • Dab product

Table 1: Cannabis Extraction Ingredients & End Products

Crude oil doesn't require further processing after the extraction is performed. In this case, lower grade cannabis material is preferable and chlorophyll may be less of an issue. Ethanol extraction, which maximizes throughput and yield while minimizing capital cost, is ideal for crude oil production.

If your end products require a high terpene content, CO_2 extraction may be the right choice for your extraction process. Subcritical CO_2 extraction allows for the extraction of an isolated terpene fraction.

This type of oil is often called 'terp-sauce', or **high terpene extract (HTE)**. It requires high grade starting material that contains a high terpene content.

By using sub-critical pressures in a CO_2 extractor, the solvent becomes selective, and picks up less overall cannabinoids, wax and lipid content. In the subcritical range, CO_2 is also quite effective at extracting terpenoids; the resulting oil from sub-critical CO_2 extraction is mostly terpenes, and can be used to formulate products with a high terpene content.

The ethanol extraction process dissolves terpenes and cannabinoids simultaneously, resulting in a full spectrum oil. Since ethanol is typically evaporated from the oil at around 40ºC, at this temperature, some of the lighter terpene compounds can be degraded or evaporated, resulting in a strong case for the use of CO_2 extraction systems that can isolate the terpenes before the cannabinoids are extracted.

And while hydrocarbon extraction is outside the scope of this article, N-Propane can be used to produce a high terpene extract as well. The propane extraction method results in a crystalline cannabinoid component, as well as a high terpene liquid. Such a process may also be worth considering, depending on your goals.

If a high terpene content, full spectrum oil is the end goal, there are also ways to achieve this using ethanol. For example, by reducing the evaporation temperature to 35ºC or less, it is possible to protect the terpenes from damage, and prevent degradation, resulting in a full spectrum oil. However, it may also result in incomplete solvent evaporation, thus requiring longer processing time, or a second evaporation pass for complete solvent removal.

HTE processing provides an illustration of the value of using both CO_2 and ethanol in tandem; CO_2 extraction can be used as the primary extraction method, with the addition of a secondary ethanol extraction process at -40ºC after the terpenoids have been removed from the plant material.

Using ethanol rather than CO_2 for cannabinoid extraction supports greater lab efficiency, as each system can be used for their respective strengths: CO_2 for extracting HTE, and ethanol for extracting cannabinoids. Furthermore, performing ethanol extraction at cold temperatures will reduce the need for winterization after the process. Some processors even report skipping the winterization step altogether when extracting with ethanol at temperatures below -40ºC, but this is not recommended in all scenarios.

It should be noted that, of all the end products that can be derived from processing the raw cannabis plant, high terpene extract is among the most time-consuming, energy-intensive, and expensive from the perspective of up-front capital expenditure. The cost, relative to throughput, is substantially more than other end products, which points back to the business model, rather than the wisdom of crowds, as the core consideration.

Before business owners invest in equipment for producing HTE, they should be sure that they will require high terpene extract for their products and that their starting material is of sufficient quality to extract it profitably.

Ultimately, the focus on end product as the basis for selecting the extraction methods results in optimum costs relative to throughput. Businesses manufacturing edibles, beverages, capsules, topicals, distillate, isolate, or any full spectrum CBD or THC oil will not need to isolate terpenes for those products. It is almost certainly an unnecessary process, and it should not influence your buying decision unless isolated terpenes will be used in other products.

CONSIDERATION #2: THROUGHPUT COSTS

When designing any manufacturing process, throughput — in this case the volume of cannabis material that can be processed in a given timeframe — is one of the most crucial considerations to weigh against cost.

On that basis, businesses should compare various commercially available extraction systems using a common throughput metric, such as equipment cost per common measure of throughput capacity. See *Table 2: CO2 vs Ethanol Throughput Cost*

Comparison, for an example of this type of analysis, using 1,000-lbs of daily input material as the common comparison metric.

Because ethanol extractors operate at atmospheric pressures, equipment costs relative to throughput is substantially less; operating at low pressure also contributes to shorter cycle times and higher throughput for ethanol extractors, compared to CO_2 extractors.

Ethanol recovery may be performed in a separate process from extraction, which must also be taken into account. Cycle times for ethanol recovery can be lengthy and become a bottleneck if the processor opts for low cost equipment.

That said, ethanol recovery systems come in many sizes. Rotary evaporators are very cost effective and easy to install, but provide less throughput than other systems, like falling film evaporators which, while costly, provide among the highest throughput capacity available.

In one scenario, a falling film evaporator can recover 30 gallons of ethanol per hour, which is enough to process 90 pounds of plant material, a substantial throughput relative to the total cost of all the equipment required. Using this ethanol recovery rate as an example, in one 12-hour period an ethanol extraction system sized to match that recovery rate can process 1,080 pounds of organic material, at a total equipment cost of around $500,000 USD.

To achieve this same throughput using CO_2 extractors, equipment cost would exceed

	SOLUTION COMPONENTS	CAPITAL COST (APPROX, IN USD)	LBS OF THROUGHPUT (PER 18-HR SHIFT)	TOTAL EQUIPMENT COST (PER 1,000 LB OF OUTPUT)
Ethanol Extraction VENDOR A • 80L capacity	• Separator • Ethanol Storage • Filtration • Walk-in Freezer • Solvent Recovery • Extraction Booth	$374,000	700	$534,286
CO_2 Extraction VENDOR B • 90L capacity	• Extractor • Winterization & Filtration System • Walk-in Freezer • Solvent Recovery System • CO_2 Sensing & Venting system	$554,000	175	$3,165,714
CO_2 Extraction VENDOR C • 40L capacity	• Extractor • Winterization & Filtration System • Walk-in Freezer • Solvent Recovery System • Decarboxylation ovens • CO_2 Sensing & Venting system	$396,000	80	$4,950,000

Table 2: CO_2 vs Ethanol Throughput Cost Comparison

$3,000,000 USD. This is largely due to the small throughput capacity achieved by even the best CO_2 extractors in the industry. The high pressures necessary for this method render machines quite costly to manufacture. Longer cycle times also contribute to the cost of throughput.

CONSIDERATION #3: OPERATING COSTS

In operating an extraction facility the primary operational costs are cannabis material, labour, real estate, solvent costs and power consumption.

In terms of solvent cost, CO_2 has the clear, measurable advantage. Although ethanol is still required for winterization following CO_2 extraction in many cases, the volumes required to winterize are less than when using ethanol as the primary solvent.

CO_2 is inexpensive and readily available worldwide, as it is used extensively in the food industry. Similarly, food grade ethanol is also widely available, but in most countries its regulation can result in much more 'red tape' than CO_2; when food grade ethanol is used for industrial purposes, it is often not taxable the same way that it is when used for beverage manufacturing, but this usually results in submitting paperwork to a government body.

When comparing the approximate solvent costs from processing 1,000 lbs of cannabis — using CO_2 with ethanol as a secondary winterization process, versus ethanol as the primary solvent — ethanol was just over three times the cost.

In both cases, solvents are not a significant factor in the overall cost of processing. For example, if 45kg of oil was extracted from 1,000 pounds of input material, the total solvent costs for ethanol extraction would be 0.29% of revenue derived, versus 0.08% if extracting with CO_2 and winterizing with ethanol.

Another material expense for processing is power consumption. Both CO_2 and ethanol extraction processes require large chillers, heaters and pumps. These consume significant power when scaled up commercially. There is not a clear advantage on either side when it comes to power consumption when comparing the two extraction processes.

In returning to the two costs that are more impactful to profitability than solvents —real estate and labor, it's worth reinforcing the throughput advantage of ethanol extraction, resulting in the ability for processors to produce more end product with their space and workforce, keeping overhead lower, relative to output.

Labour is normally the largest expense for any business, and this is no different in the extraction sector. Packing and unpacking extraction vessels is a large portion of the labour involved with processing plant material into oil.

Because of the high pressures involved with CO_2 extraction, the vessels that contain the plant material are often small in volume, or they are very tall. Using many small extraction vessels usually requires the use of many small or medium sized CO_2 extractors. This has advantages of redundancies but also requires excessive labour to pack and unpack a large number of times.

Similarly, using fewer but larger CO_2 systems requires less frequent loading and unloading of plant material, but because of the height of the machine — some CO_2 extraction vessels can reach over 20 feet in height — the process is cumbersome. These machines take up a lot of space and are relatively expensive on a throughput basis, even compared to smaller CO_2 extractors.

Using one large system rather than multiple smaller ones also exposes the processor to added risk if the system is not performing as expected, or when it requires maintenance or repair.

Ethanol extraction, meanwhile, can be performed at atmospheric pressure, which makes for quick loading of plant material into relatively large vessels. This gives ethanol the advantage in terms of labor costs; ease of loading plant material into and out of extraction vessels is also an ergonomic benefit for machine operators, and widens the potential labor pool of operators for such machines.

It is often the case that the physical demands of loading and unloading organic matter in and out of the extraction machines is overlooked when performing cost-benefit analyses of an extraction system. As such, it is always recommended that businesses in the cannabis processing space ask equipment suppliers for demonstrations (in person or video) of systems being loaded and unloaded with plant material prior to making the investment, so the time involved in that process can be understood from a labour cost perspective.

CONSIDERATION #4: SAFETY RISKS

While CO_2 extractors generally have a strong reputation for safety, this is largely due to the engineering and design that commercially available systems undergo.

Ethanol and even hydrocarbon systems can be equally as safe as CO_2 if they are engineered and peer reviewed. A CO_2 extractor that was capable of 5000 PSI but not engineered and certified for those pressures could potentially be just as dangerous as a do-it-yourself ethanol extractor.

The promotion of the safety of CO_2 extractors can contribute to complacency; it is of utmost importance that operators understand and respect the risks posed by these machines and the pressures within which they operate. The risk of an adverse event can rise dramatically with just a single modification to the engineer-approved design.

There is an equal misunderstanding of the risks associated with the use of solvents in industrial settings. Because solvents like ethanol, N-Butane or N-Propane operate at low (or atmospheric) pressure, they are favored among do-it-yourself extractor builders.

Businesses and individuals in this category often do not use professionally engineered systems, and thus, due to a lack of safety standards, they often violate basic safe practices, causing fires and explosions. This latent risk from unregulated or illegal operations has contributed to the fear and stigma associated with these solvents.

Engineered, certified systems, however, should never be placed in the same category as do-it-yourself operations. In practice — in the regulated cannabis marketplaces — any extraction system using either high pressure or flammable liquids can be extremely dangerous unless engineers are involved in the design of the systems. Ethanol, CO_2, and even hydrocarbon extraction systems are equally safe when the process is engineered to meet all fire and pressure codes, and when the operators are following safe procedures.

Fire code compliance drives the need for ventilation hoods or extraction booths in ethanol and hydrocarbon extraction, adding to installation costs. Similarly, pressure code compliance and ventilation for CO_2 systems may add to the cost of installation. Both ethanol extraction and CO_2 extraction requires ventilated rooms. The need for a Class 1, Division 2 (C1D2) rated room for ethanol extraction does not materially 'tip the scales' of capital cost relative to throughput.

CONCLUSION

Much like consumers in the early adoption cycle of new technologies, processors of cannabis extracts can be overwhelmed by the myriad emerging standards in this sector, and more easily influenced by the 'hype' that accompanies such a formative marketplace.

Business leaders must remember that every end product has a unique process, and thus it is critical to first carefully define the desired end product, working backwards to optimize their process from there.

Without thinking about the end product, there's a great risk of employing an inefficient process, and needlessly expending valuable cash and human resources in the race towards commercial viability and marketplace competitiveness.

The good news for businesses that are deliberate about process design and optimization is that it's possible to maintain a focus on quality while simultaneously minimize the cost of manufacturing, and maximizing throughput. This approach, in fact, may be the only way for smaller, less capitalized players to gain a competitive advantages over larger, venture-backed organizations.

Although the cannabis industry is in its early years, it's already ripe for disruption!

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