Infusion Cost per milligram of CBD

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Abstract

This document demonstrates how to calculate the cost to infuse CBD, on a per milligram basis, using the HHI Counter-current Lipid Infusion systems. With wholesale and retail costs extending from $0.03 to 0.15 per infused milligram, HHI believes significant opportunity exists to make these products with the E4 Infusion system at production costs approaching and dropping even further below $0.001 per infused milligram. Notably, we show in this document that, for both retail and wholesale price estimates, the HHI E4 infusion system can pay for itself with less than a week of processing time. Specific focus is given to the output of the E4 Infusion system yet the equations derived are general and can also be adapted to the E1 infusion system by changing the appropriate input parameters.

I Process parameter values

The main costs to make product with the HHI E4 Infuser are hemp, carrier oil, and labor. The process parameter values that will be used to calculate these costs are given in Table 1. The labor price of $30/hr accounts for one technically proficient employee that performs both infusion and post-refinement processes like decarboxylation and filtration. In-house tests at HHI have shown that 9 lb batches with cycle times of 80 minutes satisfactorily extract hemp (efficiency $E > 0.90$) and recover oil from squeezed hemp (lost oil ratio $f \approx 0.9$). The hemp price of $\mathcal{P}_b$=$2/[(mass % CBD)·(lb hemp)] is taken from the range of 0.4 to 2.5 $2/[(mass % CBD)·(lb hemp)] reported in January 2020 by Hemp Benchmarks for aggregate CBD hemp. On a per pound basis, the 6% hemp assumed in table 1 corresponds to $12/lb by setting $\mathcal{P}_b$=$2/[(mass % CBD)·(lb hemp)]. The carrier oil price of $5/lb is based on a cost of $2100 to receive a single 55 gallon (420 lbs) drums of organic MCT oil. The product oil potency of 5% is chosen to reflect the higher end of lipid-infused retail products that are currently sold. (In the calculations below, mass fractions are used instead of mass % for hemp and oil potency to ensure the overall cost calculation is dimensionally consistent. To do so, the hemp price is written terms of mass fraction CBD instead of mass percent CBD to ensure dimensional consistency of the production cost.) Finally, the infusion system operates most efficiently when three columns are actively infusing oil with plant compounds. To do so requires a "system fill" about 15 gallons (190 lbs) of carrier oil which is an upfront, fixed cost.

II Labor cost

The labor cost $\mathcal{C}_l$ ($) to operate the Infuser can be written as

$$\mathcal{C}_l = \frac{\mathcal{P}_l \, m_b \, t_c}{m_c} \tag{II.1}$$

where $\mathcal{P}_l$ ($/hr) is the hourly labor price, m_b (lbs) is the amount of hemp to be processed, t_c (hrs/cycle) is the cycle time, and m_c (lbs/cycle) is the hemp charged to the system per cycle.

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Symbol	Quantity	Units	Sample Value
$\mathcal{P}_l$	labor price	\$/hr	30
t_c	batch cycle time	hr	1.2
m_c	hemp batch size	lbs	9
$\mathcal{P}_b$	hemp price	$\frac{\$}{\text{(mass fraction CBD)} \cdot \text{(lb hemp)}}$	200
m_b	total hemp production amount	lbs	180
c_b	hemp potency	mass fraction CBD	0.06
$\mathcal{P}_o$	carrier oil price	\$/lb	5
c_p	product oil potency	mass fraction CBD	0.05
f	ratio of lost oil to charged hemp	$\frac{\text{lbs oil lost}}{\text{lbs hemp charged}}$	0.9
m_f	system fill oil	lbs	190
E	extraction efficiency	$\frac{\text{lbs CBD infused}}{\text{lbs CBD charged}}$	0.9

Table 1: Notation, units, and sample values

To carry out a 180 lb production run, II.1 evaluates to

$$\text{labor:} \qquad \mathcal{C}_l = \frac{\left(\frac{\$30}{\text{hr}}\right)(180 \text{ lbs hemp})\left(\frac{1.2 \text{ hrs}}{\text{cycle}}\right)}{\frac{9 \text{ lbs hemp}}{\text{cycle}}} = \$720 \tag{II.2}$$

III Biomass cost

The hemp cost $\mathcal{C}_b$ (\$) is

$$\mathcal{C}_b = \mathcal{P}_b \, c_b \, m_b \tag{III.1}$$

where $\mathcal{P}_b$ (\$/[(mass fraction CBD)·(lb hemp)]) is the hemp price and c_b is the hemp potency in units of mass fraction CBD. For 6% hemp at \$200/[(mass fraction CBD)·(lb hemp)] we have

$$\text{hemp:} \qquad \mathcal{C}_b = \left(\frac{\$200}{\text{mass fraction CBD} \cdot \text{lb hemp}}\right)(0.06 \text{ mass fraction CBD})(180 \text{ lbs hemp}) = \$2160 \tag{III.2}$$

IV Carrier oil cost

The amount of carrier oil required to process m_b lbs of hemp includes oil lost to hemp (m_{loss}, lbs), oil required to fill the Infuser (m_f, lbs), and oil required to make the potent product oil (m_p, lbs). These three components are written as

$$m_o = m_p + m_{loss} + m_f = \frac{E \, m_b \, c_b}{c_p} + f \, m_b + m_f \tag{IV.1}$$

where E (lbs CBD infused/lbs CBD charged to system) is the infusion efficiency, c_p (mass fraction CBD) is the operator-specified product oil potency, f (lbs MCT lost/lb hemp charged) is a factor that relates the expected carrier oil loss to the charged hemp, and m_f is the amount of oil required to fill the infuser. In IV.1, the following relation was used to substitute an expression for m_p:

$$m_p\, c_p = E\, m_b\, c_b \tag{IV.2}$$

We refer to this expression as the *production equation* because it describes how much product oil at a specified potency can be made from a certain amount of hemp with known potency. The efficiency E simply indicates that a fraction (90% for the E4 Infuser) of the cannabinoids in the hemp will be infused into the product oil.

Using $\mathcal{P}_o$ (\$/lb) to denote the carrier oil price, the total oil cost is

$$\begin{aligned} \mathcal{C}_o &= \mathcal{P}\, m_o \\ &= \mathcal{P}_o \left(\frac{E\, m_b\, c_b}{c_p} + f\, m_b + m_f \right). \end{aligned} \tag{IV.3}$$

Using the process parameter values specified in table 1, the amount of carrier oil consumed for a 180 lb production run, via IV.1, is

$$\begin{aligned} \text{carrier oil:} \qquad m_o &= \frac{\left(\frac{0.9 \text{ lbs CBD out}}{\text{lb CBD in}}\right)(180 \text{ lbs hemp in})\left(\frac{0.06 \text{ lbs CBD in}}{\text{lb hemp in}}\right)}{\left(\frac{0.05 \text{ lbs CBD out}}{\text{lb oil out}}\right)} \\ &\quad + \left(\frac{0.9 \text{ lbs lost oil}}{\text{lb hemp in}}\right)(180 \text{ lbs hemp in}) + (190 \text{ lbs system fill oil}) \\ &= (194.4 \text{ lbs product oil out}) + (162 \text{ lbs lost oil}) + (190 \text{ lbs system fill oil}) \\ &= 546.4 \text{ lbs total carrier oil required} \end{aligned} \tag{IV.4}$$

and the total carrier oil cost, via IV.3, is

$$\begin{aligned} \text{carrier oil:} \qquad \mathcal{C}_o &= \frac{\$5}{\text{lb}}(546.4 \text{ lbs}) \\ &= \$2732. \end{aligned} \tag{IV.5}$$

In IV.4, the mass fractions of the input hemp and output oil are written in terms of (lbs CBD)/(lb material) to clarify the dimensional consistency of the expression.

V Total cost and cost per mg

Combining the labor, hemp, and carrier oil costs, the total cost to process m_b lbs of hemp into m_p lbs of oil with cbd potency of c_p is

$$\begin{aligned} \mathcal{C}_{tot} &= \mathcal{C}_l + \mathcal{C}_b + \mathcal{C}_o \\ &= \frac{\mathcal{P}_l\, m_b\, t_c}{m_c} + \mathcal{P}_b\, c_b\, m_b + \mathcal{P}_o \left(\frac{E\, m_b\, c_b}{c_p} + f\, m_b + m_f \right) \\ &= \$720 \text{ (labor)} + \$2160 \text{ (hemp)} + \$2732 \text{ (carrier oil)} \\ &= \$5612 \end{aligned} \tag{V.1}$$

Using the factors of 453592 and 100 to convert from lbs to milligrams and from mass percent to mass fraction, respectively, the total number of infused milligrams is

$$\begin{aligned} N_{mg} &= E\, m_b\, c_b \times 453592 \\ &= \left(\frac{0.9 \text{ lbs CBD out}}{\text{lb CBD in}}\right)(180 \text{ lbs hemp in})\left(\frac{0.06 \text{ lbs CBD in}}{\text{lb hemp in}}\right) \times 453592 \\ &= 4.41 \times 10^6 \text{ mg cbd}. \end{aligned} \tag{V.2}$$

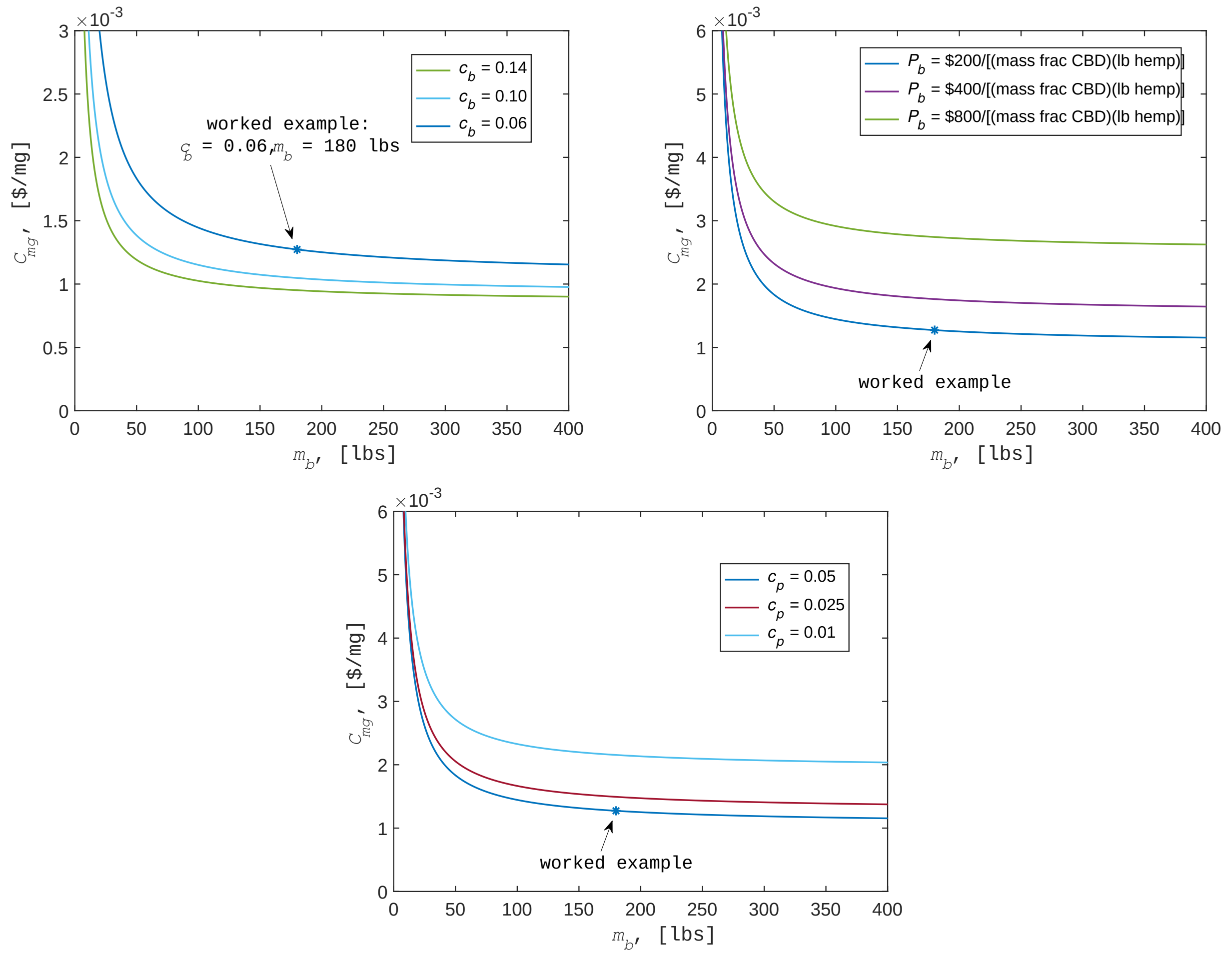

Figure 1: Cost per milligram as function of production run size and varying (a) hemp potency, (b) hemp price, and (c) output oil potency.

and the total cost per infused milligram is

$$\begin{aligned} C_{mg} &= \frac{C_{tot}}{N_{mg}} \\ &= \frac{\$5612}{4.41 \times 10^6 \text{ mg cbd}} \\ &= \$0.0013 \text{ per infused mg cbd.} \end{aligned} \tag{V.3}$$

VI Cost per milligram analysis

Writing out the full expression for $\mathcal{C}_{mg}$ (V.3) we have

$$\begin{aligned}\mathcal{C}_{mg} &= \frac{\mathcal{C}_{tot}}{N_{mg}} \\ &= \frac{\dfrac{\mathcal{P}_l\, m_b\, t_c}{m_c} + \mathcal{P}_b\, c_b\, m_b + \mathcal{P}_o \left(\dfrac{E\, m_b\, c_b}{c_p} + f\, m_b + m_f\right)}{E\, m_b\, c_b \times 453592} \\ &= \frac{1}{453592}\left[\frac{\mathcal{P}_l\, t_c}{E\, m_c\, c_b} + \frac{\mathcal{P}_b}{E} + \mathcal{P}_o\left(\frac{1}{c_p} + \frac{f}{E\, c_b} + \frac{m_f}{E\, m_b\, c_b}\right)\right].\end{aligned} \tag{VI.1}$$

which provides further general insight in to how the cost per infused milligram depends upon the process parameters. For instance, the first term inside the square brackets, $\mathcal{P}_l\, t_c/(E\, m_c\, c_b)$, measures the labor contribution to $\mathcal{C}_{mg}$; it increases with labor cost and cycle time ($\mathcal{P}_l$, t_c) while decreasing with infusion efficiency, batch size, and hemp potency (E, m_c, c_b). The second term, $\mathcal{P}_b/E$, quantifies hemp cost and increases with hemp price ($\mathcal{P}_b$) while decreasing with infusion efficiency (E).

The three terms inside the parentheses that multiply the oil price ($\mathcal{P}_o$) measure the carrier oil contributions to $\mathcal{C}_{mg}$. Naturally, the oil cost per milligram increases with the oil price $\mathcal{P}_o$. The oil cost more intricately depends on the three terms in the parentheses that it multiplies. Recall first that the forms of these terms differ from how they appear in (V.1) for $\mathcal{C}_{tot}$ because they have been scaled by the total number infused milligrams, N_{mg}). The first of these terms, $1/c_p$, arises from the product oil contribution to the total oil requirement and strictly decreases as c_p increases because a higher output potency implies that less carrier oil is required. The second term, $f/(E\, c_b)$, is connected to the amount of oil lost to spent hemp; it is proportional to the lost oil ratio f and inversely proportional to the extraction efficiency and hemp potency (E, c_b). This term decreases with infusion efficiency and hemp potency because higher values of these parameters imply having to run less hemp, and, accordingly, less oil lost to spent hemp. Last, the term pertaining to the system fill mass, $m_f/(E\, m_b\, c_b)$, measures the the system fill contribution to $\mathcal{C}_{mg}$ and is the only term in VI.1 that depends the production run size, m_b. This occurs because the system fill is an upfront *fixed* cost. With m_b appearing in the denominator, it is clear that the contribution of the system fill to $\mathcal{C}_{mg}$ will become negligible for *large* production runs (i.e., large m_b).

Some of the trends of cost per milligram with respect to varying process parameters are depicted in panels (a) - (c) of Figure 1. In each panel, $\mathcal{C}_{mg}$ is plotted as a continuous function of the production size m_b to highlight the decaying influence of the system fill oil requirement. Panel (a) notably shows that infusion costs decrease with biomass potency. This behavior depends on being able to secure hemp at a constant cost (per cbd content). Panels (b) and (c) highlights the negative influence of biomass price and output oil potency on production costs.

VII Retail and wholesale infusion prices

Retail data on lipid-infused hemp products are provided in Table 2. The table focuses on infused oil tinctures. However, many of the listed companies also formulate additional products such as topicals, edibles, lotions, etc. The histograms in figure 2 show the distributions of the table data in addition to their min, max, and mean values.

Focusing on the price per mg of these products, the average cost per mg cbd is \$0.089 which exceeds the HHI infusion costs shown in figure 1 by a factor of nearly 50 to 100. Since July since these prices were last compiled, Alternative Health and CannaAid have emerged with the lowest prices for retail lipid infusions at \$0.0083 to \$0.04 per infused milligram. Sunsoil, a well-established manufacturer of lipid infusions retails its products for \$0.05 per mg cbd.

The distributions of total doses, total cbd, and retail product costs are skewed by a "bulk" 32 oz. bottle by Palmetto Harmony infused to 20 mg cbd/mL for \$1000 (i.e., 18920 mg cbd at 5.3 cents per milligram). Still, the price per

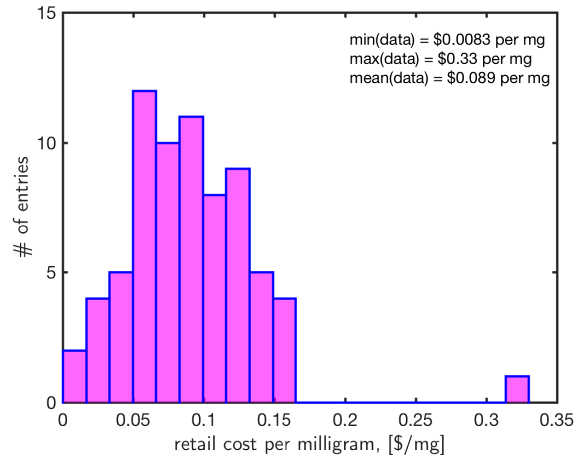

Figure 2: Histogram cost per milligram CBD in table 2.

mg cbd for the Palmetto Harmony bulk bottle is nearly double the wholesale costs that HHI is aware of indicating a gallon of 50 mg cbd/mL oil (total of $\tilde{1}$90000 mg cbd) sells for $5000 (2.6 cents per milligram). **This wholesale cost of 2.6 cents per milligram is no longer lower than all of the retail prices (e.g., CannaAid) shown in table 2. Yet the retail lipid oil prices per milligram, including CannaAid, are still far exceed infusion costs with HHI equipment.**

VIII Profit and return on investment

Profit naturally increases for retail sale of oil compared to wholesale at the expense of added up-front costs of business. In this section we consider both cases by defining the wholesale profit per milligram, π_w, as

$$\pi_w = \mathcal{W}_{mg} - \mathcal{C}_{mg} \tag{VIII.1}$$

and the wholesale profit per milligram, π_w, as

$$\pi_r = \mathcal{R}_{mg} - \mathcal{B}_{mg} - \mathcal{C}_{mg} \tag{VIII.2}$$

where the wholesale and retail prices per milligram, $\mathcal{W}_{mg}$ and $\mathcal{R}_{mg}$, respectively, will be estimated considering the analysis of section VII. In equation VIII.2 for retail profit, the term $\mathcal{B}_{mg}$ is included to describe bottling, marketing, and any other costs associated with bringing a wholesale oil to the retail market. In equations VIII.2 and VIII.2, $\mathcal{C}_{mg}$ is the cost per infused milligram as defined in equations V.3 and discussed further in section VI.

Using the expressions for π_w and π_r, we can calculate the amount of time required, $\tau_{\mathcal{I}}$, to pay off an investment of amount $\mathcal{I}$ [$] with the HHI Infusion process. Simply, the time requirement can be written

$$\tau_{\mathcal{I}} = m_{\mathcal{I}} \times \frac{t_c}{m_c} \tag{VIII.3}$$

where $m_{\mathcal{I}}$ is the amount of biomass required to infuse an amount of cbd with value equal to the investment and the fraction $\frac{t_c}{m_c}$ is the inverse of the Infusion biomass processing capacity. The amount of biomass required, as a function of the input biomass (c_b) and output oil (c_p) potencies, can be by first setting the investment cost equal to the profit

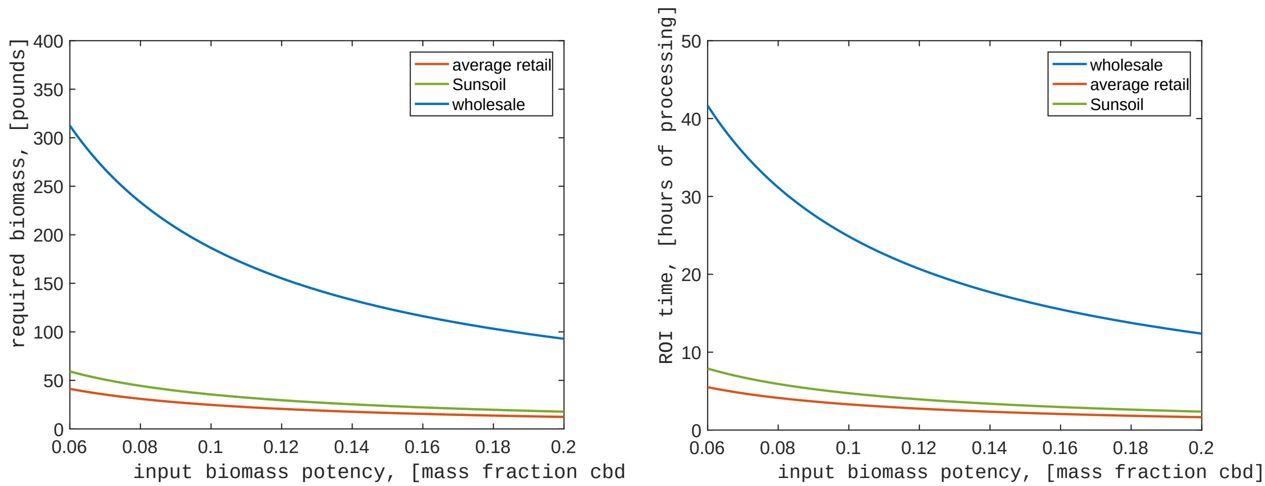

Figure 3: Return on investment biomass and time requirements as functions of input biomass potency.

generated from a fixed amount of infused cbd, viz.,

$$
\begin{aligned}
\mathcal{I} &= \pi_w\, N_{mg} \\
&= \left(\mathcal{W}_{mg} - \mathcal{C}_{mg}\right)\, N_{mg} \\
&= \mathcal{W}_{mg}\, N_{mg} - \mathcal{C}_{tot} \\
&= \mathcal{W}_{mg}\,(E\, m_{\mathcal{I}}\, c_b \times 453592) - \left(\frac{\mathcal{P}_l\, m_{\mathcal{I}}\, t_c}{m_c} + \mathcal{P}_b\, c_b\, m_{\mathcal{I}} + \mathcal{P}_o\left(\frac{E\, m_{\mathcal{I}}\, c_b}{c_p} + f\, m_{\mathcal{I}} + m_f\right)\right) \\
&= m_{\mathcal{I}}\left[\mathcal{W}_{mg}\, E\, c_b \times 453592 - \left(\frac{\mathcal{P}_l\, t_c}{m_c} + \mathcal{P}_b\, c_b + \mathcal{P}_o\left(\frac{E\, c_b}{c_p} + f\right)\right)\right] - \mathcal{P}_o\, m_f.
\end{aligned}
\tag{VIII.4}
$$

Here, the biomass production run size m_b has been replaced with the amount of biomass required, $m_{\mathcal{I}}$, to pay off an investment $\mathcal{I}$. The last line of VIII.4 has been written so that $m_{\mathcal{I}}$ can easily be solved for and substituted back in to VIII.3 for $\tau_{\mathcal{I}}$. Doing so we have

$$
m_{\mathcal{I}} = \frac{\mathcal{I} + \mathcal{P}_o\, m_f}{\mathcal{W}_{mg}\, E\, c_b \times 453592 - \left(\frac{\mathcal{P}_l\, t_c}{m_c} + \mathcal{P}_b\, c_b + \mathcal{P}_o\left(\frac{E\, c_b}{c_p} + f\right)\right)} \tag{VIII.5}
$$

and

$$
\tau_{\mathcal{I}} = \frac{\mathcal{I} + \mathcal{P}_o\, m_f}{\mathcal{W}_{mg}\, E\, c_b \times 453592 - \left(\frac{\mathcal{P}_l\, t_c}{m_c} + \mathcal{P}_b\, c_b + \mathcal{P}_o\left(\frac{E\, c_b}{c_p} + f\right)\right)} \times \frac{t_c}{m_c}. \tag{VIII.6}
$$

The time required to generate return on investment will now be discussed for wholesale and retail production. For wholesale production, equation VIII.6 directly applies with $\mathcal{W}_{mg} = \$0.026$, see section VII. For retail production, we replace $\mathcal{W}_{mg}$ with $\left(\mathcal{R}_{mg} - \mathcal{B}_{mg}\right)$ in VIII.5 and VIII.6 and will consider both the averaged data ($\mathcal{R}_{mg}$=\$0.098 per mg cbd, 1090 mg per bottle) and Sunsoil data ($\mathcal{R}_{mg}$=\$0.05 per mg cbd, 1200 mg cbd per bottle). To estimate $\mathcal{B}_{mg}$ we assume an added cost of \$10 per bottle which equates to $\mathcal{B}_{mg} = \$0.098$ per mg cbd (averaged data) and \$0.083 per mg cbd (Sunsoil).

Figure 3 presents the biomass ($m_{\mathcal{I}}$) and processing time (τ_I) required to make product with value equal to the Infusion system price, $\mathcal{I}$=\$190000. It can clearly be seen these ROI requirements decrease as the input biomass potency increases because of reduced carrier oil and labor costs. These results were calculated by setting output oil potencies for wholesale, average retail, and Sunsoil to 50, 23, and 20 mg cbd/g, respectively. Although tuning the process to produce higher output potencies can decrease the carrier oil cost, adjustment of this parameter did not significantly affect the requirements shown in figure 3. Most importantly, figure 3 shows the HHI system can pay for itself in a very short period of time of between 5 and 40 hours of infusion time.

Appendices

A Retail lipid-infused hemp oil data

Company	Product	Potency $\left[\frac{\text{mg cbd}}{\text{dose}}\right]$	Doses [#]	Total CBD [mg cbd]	Price [$]	Price per mg $\left[\frac{\$}{\text{mg cbd}}\right]$
Sunsoil	cinnamon	20	60	1200	60	0.050
	unflavored	20	60	1200	60	0.050
	chocolate mint	10	60	600	30	0.050
	citrus	10	60	600	30	0.050
	unflavored	10	60	600	30	0.050
Boulder Creek	natural cbd oil	50	30	1500	85	0.057
	chocolate mint	50	30	1500	85	0.057
	orange cinnamon	50	30	1500	85	0.057
TEWNC	250 mg hemp oil	17	15	250	33	0.132
	500 mg hemp oil	17	30	500	59	0.118
	1000 mg hemp oil	17	60	1000	105	0.105
	2000 mg hemp oil	17	120	2000	190	0.095
Functional Remedies	Full Spectrum hemp oil	17	30	500.1	46	0.092
	Full spectrum hemp oil	33	30	999.9	79	0.079
Papa and Barkley	Releaf drops	30	15	450	35	0.078
	Releaf drops	30	30	900	60	0.067
Palmetto Harmony	Orange Hemp Oil	20	100	2000	185	0.092
	Orange Hemp Oil	20	30	600	80	0.133
	Hemp Oil	20	100	2000	185	0.092
	Hemp Oil	20	30	600	80	0.133
	Hemp Oil BULK	20	946	18920	1000	0.053
Sprout Hemp CBD	Full spectrum tincture	8	30	250	34.2	0.137
	Full spectrum tincture	17	30	500	54.2	0.108
	Full spectrum tincture	33	30	1000	74.2	0.074
	Willie's Remedy	10	30	300	48	0.160
Organic4RX	Full Spectrum CBD Oil	17	30	500	60	0.120
	Full Spectrum CBD Oil	25	30	750	75	0.100
	Full Spectrum CBD Oil	33	30	1000	99	0.099
	Full Spectrum CBD Oil	50	30	1500	129	0.086
Full Flower Hemp	Balance	8	30	250	38	0.152
	Balance	17	30	500	65	0.130
	Balance	33	30	1000	110	0.110
Iron Horse Organics	Super concentrate	17	30	500	69	0.138
	extra strength	37	30	1100	85	0.077
	holistic	9	60	550	72	0.131
	pet remedy	9	60	550	70	0.127
Crucial Hemp	CBD Coconut oil	4	111	450	32	0.071
	CBD oil - daily health extra	33	30	1000	88	0.088
	Tincture	7	30	200	24	0.120
	Tincture	7	120	800	68	0.085
	Tincture for pets	7	30	200	24	0.120
	Tincture for pets	7	120	800	68	0.085
	CBD coconut oil for pets	4	111	450	32	0.071
Vitamia Hemp	Pet Tincture	24	30	710	40	0.056
	softgels	25	30	750	60	0.080

	softgels	25	60	1500	90	0.060
Sopris	full spectrum cbd oil	25	30	750	64	0.085
	full spectrum cbd oil	25	15	375	40	0.107
	full spectrum cbd oil	25	60	1500	112	0.075
	serenity	10	60	600	64	0.107
Onda Wellness	Hemp Immunity Infusion	5	60	300	48	0.16
	Whole Hemp Infusion	10	15	150	21	0.14
	Whole Hemp Infusion	50	60	3000	285	0.095
	Whole Hemp Infusion	10	60	600	78	0.130
Whitt Hemp Company	Hemp tincture	16.7	24	400	33	0.083
	Hemp tincture	16.7	60	1000	53	0.053
Eat Moore's Produce	Coconut Hemp Tincture	-	-	400	50	0.125
	Hemp serum	-	-	1000	90	0.09
	Hemp serum	-	-	500	60	0.12
Alternative Health	Hemp Tincture	17	15	250	12	0.048
	Hemp Tincture	17	30	500	20	0.04
	Hemp Tincture	17	60	1000	30	0.03
CannaAid	Original Tincture	10	15	150	5	0.033
	Original Tincture	10	30	300	7.50	0.025
	Original Tincture	20	30	600	10	0.017
	Original Tincture	40	30	1200	20	0.017
	Original Tincture	80	30	2400	35	0.015
	Original Tincture	100	120	12000	100	0.0083
Awakened	Everyday Hemp Drops	9	15	135	45	0.33
Cultivated Hemp Co.	White Label	17	30	500	25	0.05
	Silver Sessions	33	30	1000	45	0.045
	Gold Standard	67	30	2000	90	0.045
	Pet Formula	10	30	300	22	0.073

Table 2: Retail products prices and potencies.