Becoming a Net-Zero Emissions Maple Syrup Producer

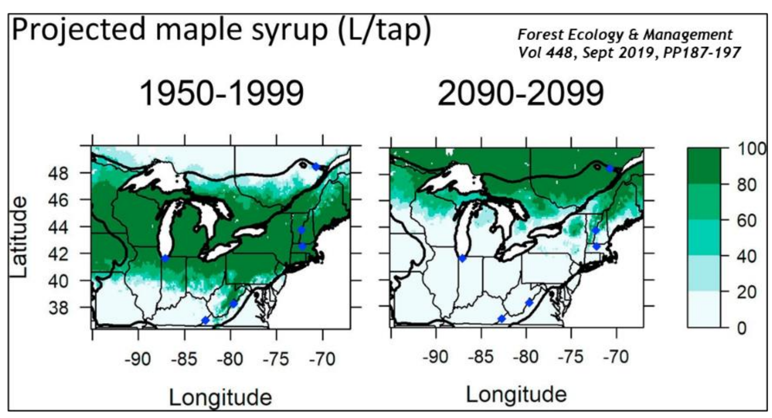
Paul Renaud & Yves Lauzon

Sep 2021

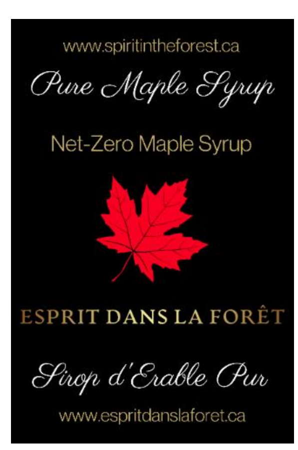
Introduction

This article is intended for maple syrup producers who are interested in reducing their Green House Gas (GHG) footprint and possibly even becoming a net-zero emissions producer. It is not intended to debate the need for climate action, as that is well-documented elsewhere; nor is it intended to stimulate debate on whether individual emissions matter -- either you care enough about nature to want to take individual action to reduce your carbon footprint (i.e. part of the solution vs. part of the problem), or you do not.

Climate change hits maple syrup producers both by shortening the season and via volatile daily swings in temperature that reduces the number of days that sap will flow during the shorter season. The 2021 season is a "good" example of both. Research by Environment Canada and the Province of Quebec into the impact of climate change on the maple syrup industry also highlights that the sugaring season is starting earlier and earlier over time. They estimate that if climate change is not abated, the fall and spring windows for sap flows will merge within 40 – 50 years and that the feasible environment for maple syrup production will shift northward as illustrated below (note that the chart shows sap, not syrup, yield per tap). Also, since sugar is a natural anti-freeze for trees, warmer winters will reduce the winter-hardiness of maples, resulting in less syrup yield. Every 1'C increase in avg summer temperature reduces Brix in the following season by 0.1' Brix. So many producers are well-motivated to take affirmative climate action.



Some producers may wonder if it is even possible to become a net-zero producer since the evaporator is at the centre of the process and burning fuel to boil sap seems inevitable. The good news is that our "Spirit in The Forest" (www.espritdanslaforet.ca) maple syrup operation is proof that achieving net-zero is indeed well within reach of most maple syrup producers. Although we are a small-scale maple syrup producer that will not likely grow beyond the 100 – 200 tap category, many of the techniques that we practice are scalable and may be of benefit to larger-, as well as smaller-, sized producers. We are happy to collaborate with different sized producers to share our experience further with them.



Other producers may believe their production is already carbon neutral. If so, we would like to help them verify that to be the case by using internationally recognized practices for carbon accounting. The resources in the toolkit available on our website will help them do that, or may expose emissions that they have not yet addressed.

What Exactly Does Net-Zero Mean?

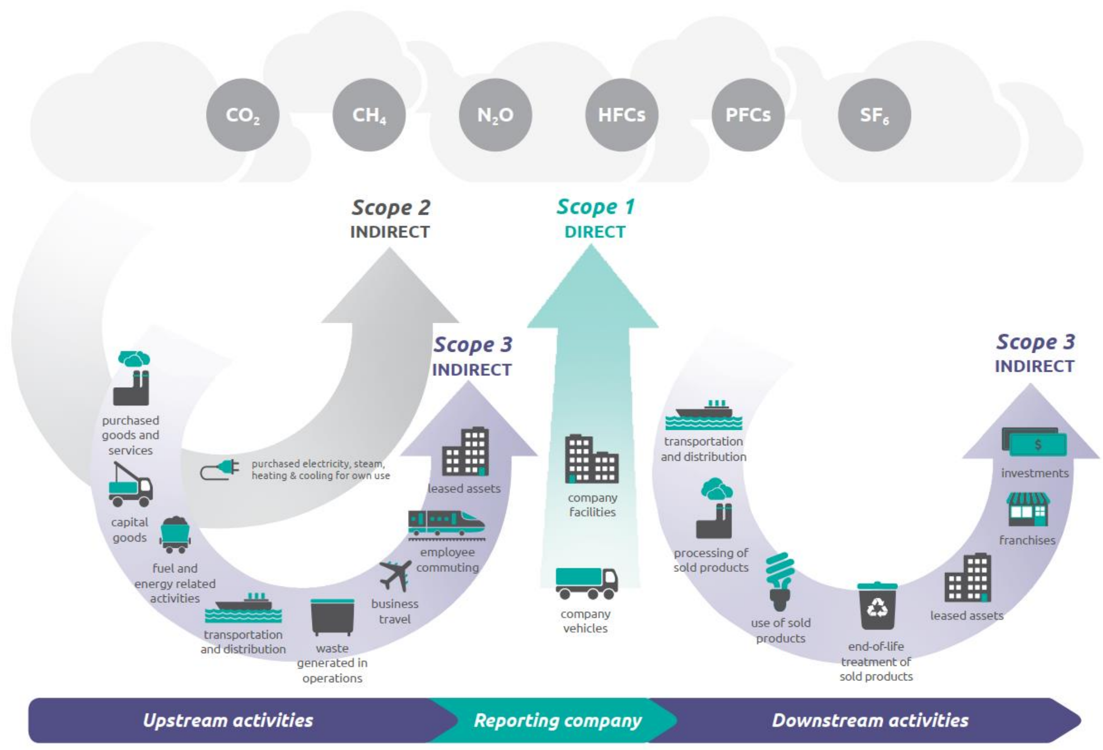
A zero-emissions process is one in which no GHG[1] are released into the atmosphere. By contrast, a net-zero emissions process is one in which the amount of GHG released is less than the amount of GHG sequestered. In maple syrup production the evaporator is the main source of emissions and the mature maple trees that we tap are a natural mechanism for sequestering carbon.

According to the internationally recognized GHG Protocol for calculating carbon footprint (see also the illustration below):

- *Scope 1* emissions refer to the emissions directly produced by your maple syrup operation, for example burning wood, fuel oil, or propane in your evaporator. It also includes the direct emissions from supporting activities such as cutting & splitting firewood for your evaporator, tapping trees, transporting maple sap to the evaporator, cleaning & washing up, and transporting your syrup to market.
- *Scope 2* emissions refer to the emissions indirectly produced by your maple syrup operation from your consumption of electricity and fuels. Depending on how your provincial Hydro generates electricity, indirect emissions may be low or moderate. Fossil fuels consumed have lifecycle emissions from extraction (in addition to the emissions from combusting them) that must also be counted.
- *Scope 3* emissions refer to you indirect emissions via upstream activities of your suppliers (for example the bottles and other packaging that you purchase to contain your finished product) and any downstream activities of your channel to market and your customers using your product (e.g. final processing & canning, transport of your product to market by others, etc.). Downstream emissions also include emissions from the disposal of waste generated in operation or arising from the consumer's disposal of your packaging.

[1] The GHG consist of several gases (CO2, Methane, Nitrous Oxide, and Halocarbons) however since CO2 is most prevalent, it is common to refer to them as CO2 Equivalents (CO2e). Since the primary emission from burning wood is Carbon Dioxide (CO2), which is the major GHG gas that needs to be mitigated in maple syrup production, we will focus on CO2 as the primary GHG to be managed. The mitigation actions for CO2 will in virtually all cases also mitigate the emission of the less common GHG arising from a maple syrup operation.

Figure [1.1] Overview of GHG Protocol scopes and emissions across the value chain



Since this article is about being accountable for and reducing our own emissions, we will examine Scope 1 and 2 emissions in-depth. Although calculation of Scope 3 emissions is currently impossible to do exactly, due to lack of disclosure by suppliers, we will discuss how to mitigate risk from Scope 3 emissions from them and how to reasonably account for that risk in your emission calculations.

- Down the road it is likely that companies will ultimately be required by regulation to declare their emissions per unit product so that the downstream users of those products will be able to calculate their Scope 3 emissions.
- For example, the carbon footprint of a disposable tap, lateral lines, bottles, etc. are all Scope 3 emissions that will not likely be disclosed without regulations that require suppliers to disclose the extent of GHG emissions inherent in each of their products sold.

Calculating the Carbon Footprint of Your Maple Syrup Operation

The carbon footprint calculation at a high-level is simple:

- Determine the amount of carbon sequestered by your trees
- Subtract your Scope 1 and Scope 2 emissions and
- If the result is less than zero and, if you allow some room for Scope 3 emissions yet to be determined, you have achieved Net-Zero
- If your result is above zero, consider ways to reduce your Scope 1 emissions as these will have the greatest room for improvement. The highest return for improvement will be found in opportunities to reduce the amount of sap that you have to boil and to improve your management of heat while boiling.

If your result is deeply negative, you may be able to sell carbon credits to others who need to use credits from others to achieve their own net-zero goals. That is more complicated endeavour that typically requires paying high certification fees to third-party auditors. Currently this is unlikely to be economically feasible for most producers to do on their own but will become more feasible down the road with better standards for carbon audits and lower costs due to more competition among auditors. Initiatives from forestry associations such as the ASFQ's PIVOT project in collaboration with the Univ. of Laval (www.projectforestierepivot.com) are emerging that facilitate obtaining carbon credits via a shared programme.

In our case, we are deeply carbon-negative because we also manage a large woodlot in addition to our sugarbush, however we but don't bother selling credits -- instead we take comfort in the fact that we are doing more than our fair share to make our climate livable for our kids and grandchildren.

It is easy to do the carbon calculation in the metric system as all the necessary coefficients for conversion can be readily found in metric units. Since many Canadian producers work in non-metric units (e.g. cords of wood) we convert into metric as needed.

Calculating Carbon Sequestration

The good news for maple syrup producers is that we only tap mature trees, and those same trees are highly effective, natural, carbon sequestration engines that cost us nothing to maintain beyond what we would otherwise do to manage our sugar bush.

The University of New Mexico published a paper that details how to calculate the volume and weight of carbon in a tree based on its size and, in turn how to use the molecular weight ratio in converting CO2 into stored carbon used in annual growth of that tree. A link to that paper can be found on our website if you care to see the details as we will only show the final equations in this article.

Consider a maple tree who is at the minimum tapping diameter of 11 inches (35" circumference) at breast height:

- A 92 ft maple tree with 11" diameter has an above ground weight of $0.15 \times (11^2) \times (92) = 1,714$ lbs.
- The roots of that tree proportionally weigh on average 20% of the above ground weight, so the total green weight of that tree is 1.2 x 1714 = 2,057 lbs.
- The average dry weight across all tree species is 72.5% of the total green weight, and the average carbon content of a maple tree is 50%, so the total carbon in the tree is 2057 x 0.725 x 0.5 = 746 lbs.
- The molecular weight ratio of CO2 to Carbon is 3.663, so the amount of CO2 sequestered by that the tree to-date is 3.663 x 746 = 2,731 lbs. Over a ton of CO2!
- If that tree is 60 years old, then it on average has sequestered 2731 / 60 = 44 lbs of CO2 per year.
- In current terms, this is an understatement since a tree sequesters more carbon as a mature tree than it did when it was young. For example, running the same calculation on a 77-year-old tree with a 44" circumference, results in an annual sequestration rate of 32 kg/yr.

So, saying that the smallest tappable tree sequesters 20 Kg CO2/year (i.e., converting 44 lbs / yr to metric) is a conservative estimate and we can confidently conclude that even a young sugar bush of 100 trees will sequester a metric ton of CO2 per year.

Obviously, every sugar bush has different trees of varying sizes. Here are 3 alternatives you can employ to calculate your sequestration:

1. You can use the average size and age of the trees you tap to determine your annual rate of carbon sequestration, or
2. You can use the actual inventory and do the sequestration calculation for each using a spreadsheet (an example is available on our website). It is straightforward to take the inventory of your trees when you next tap them and recording the diameter of trees does not greatly increase the time to tap if you use pre-cut cords for measuring the different diameter ranges. Be sure to include the adjacent non-maple trees in the inventory as they sequester carbon too. Entering the totals in the spreadsheet found on our website will give you the total CO2 sequestration, or
3. You can use an actual inventory of 1 hectare (100m x 100m) that is representative of your sugarbush. It takes less than a couple of hours to inventory the distribution of trees in a hectare (by tree type & diameter) and when you multiply the amount sequestered (as calculated in the spreadsheet on our website) by the size of your sugarbush in hectares, you have a decent estimate on the amount of CO2 that your sugarbush sequesters.

As an example, if we look at the recommended number of crop trees for a well-stocked, uneven-aged, sugar bush (adapted from the Ontario Tree Marking Guide, 2004) we might have a distribution per hectare along the lines of:

	Non-Tappable Ranges / Catégories non-utilisable				*Tappable Ranges / Catégories Utilisable*												
					1	*1*	*1*	*2*	*2*	*2*	*3*	*3*	*3*	*4*		*Taps in Each Range / Entialles par Catégorie*	
Species / Espèce	12-16 in	17-21 in	22-26 in	27-31 in	32-36 in	37-41 in	42-46 in	47-51 in	52-56 in	57-61 in	62-66 in	67-71 in	72-76 in	77-81 in	> 82"		**Type**
Sugar Maple /Erable à Sucre	7	7	26	24	35	25	20	21	13	2	1	1	2			184	Maple / Erable
Oak. White / Chêne blanc		4	11	4	3	10	6	6	5	1						50	Hardwood / Feuillu
Silver Maple / Erable Argenté							2									2	Maple / Erable
Other Hardwood / Autre Feuillu																0	Hardwood / Feuillu
Other Softwood / Autre Résineux																0	Softwood / Résineux
Subtotal Trees / Arbes	7	11	37	28	38	35	28	27	18	3	1	1	2	0	0	236	Trees / Arbes
Subtotal Taps / Entailles					38	35	28	54	36	6	3	3	6	0	0	209	Taps / Entailles

Each hectare of sugar bush with this distribution will sequester 4,800 Kg of CO2 per year and support approx. 200 taps. If a large producer with over 2800 taps has 14 hectares in their sugar bush that looks like this, they would have an annual carbon budget of 68,400 Kg of CO2.

What about the mature trees you don't tap, or perhaps tap in alternating years? You can count them too since we are calculating the amount of sequestration in the same year that you harvest and process your syrup. You can also count the mature trees of other hardwood species (which have essentially the same computational characteristics as maple trees) provided you also keep them for the full year that you used them in your calculation.

Technically there is no reason why you could not also count immature trees in your sugar bush too, however, they contribute only marginally to the total amount of sequestration. For example, a 5 ft sapling that is 1.5" in diameter sequesters only 1/10 of a Kg of CO2 per year as it grows. As it grows bigger, it contributes more, but calculating your sequestration is easier if you leave them out and skipping them also ensures that your calculations are conservative.

Once you know your carbon budget, you are ready to look at your emissions.

- For example, a mid-sized producer with a 68,400 Kg carbon budget, would allow approximately a 32 cord of wood budget (If we run the emissions calculation in reverse) assuming evaporator efficiency of 50% and zero benefit from reverse osmosis (RO).
- Increasing evaporator efficiency to 75% without an RO would enable boiling the same amount of sap with only a 22 cord of wood budget. Clearly effective heat management makes a significant difference!
- Here is an example carbon budget allocation for that producer (assuming zero benefit from RO) produced by the calculator on our website.

Sequestration per Hectare	4,886	Kg CO2 / yr		**Séquestration par Hectare**
Sugar Bush Size	14	Hectares		**Grandeur d'érablierie**
Potential # Taps Per Hectare	300			**Entailles par Hectare**
Total Taps	4,200			**Entailles Totale**
Expected Syrup Yield per Tap	1	L		**Montant de Sirop Anticipée par Entaille**
Overall Carbon Budget	68,406	Kg CO2 / yr		**Budget de Carbone en Gros**
Allocated to Scope 1	95%		64,986	**Allocation pour Portées 1**
Allocated to Scope 2	3%		2,052	**Allocation pour Portées 2**
Allocated to Scope 3	2%		1,368	**Allocation pour Portées 3**
			68,406	
Carbon Budget for Boiling				**Budget de Carbonne pour Ebullition**
Wood Fuel Conversion Factor	118	KG CO2 / M BTU		*Conversion pour BTU de Bois*
BTU Budget	550	M BTU		**Budget en Millions de BTU**
Operational Data				**Les Dons d'Exploitation**
Input Brix	2.50	Brix		Brix de Sève aux Commencement
Sap to Syrup Ratio pre-RO	34.88			Rapport de Sève à Sirop avant OI
Reverse Osmosis (RO) Reduction of Sap	0%			Reduction par Osmos Inversée (OI)
Input Sap Volume	146,496	L		Volume de Sève aux Commencement
Post RO Volume	146,496	L		Volume apres OI
BTU To Evaporate 1 L	2531	BTU		BTU Necessaire pour évaporer 1 L de l'eau
M BTU Required Assuming Perfect Efficiency	370.78	M BTU		M BTU Necessaire Avec Une Efficaise Parfait
BTU Capacity of Wood Used	22.84	M BTU		BTU Potential dans le Bois Utiliser
Evaporator Efficiency Scenarios	50%		75%	**Scenarios d'efficacité**
M BTU Required	741.56		494.38	MBTU Necessaire
Fits Into Carbon Budget	No / Non		Yes / Oui	Assez de place dans budget?
Fuel Budget				**Budget de Carburant**
Wood	32.5	Cords / Cordons	21.6	Bois
Propane	31,290	L	20,860	Propane
Fuel Oil	18,751	L	12,501	Huille

Minimizing Scope 1 Emissions from Boiling Sap

Boiling sap into syrup and bottling it are the two Scope 1 activities that every producer has. Both require heating the product and this heating is likely to be your primary source of emissions. Most of the heat used is in reducing the sap into syrup.

Strategies that can be employed to mitigate heating emissions include:

- Minimize the amount of sap you need to process when producing syrup
- Use climate-friendly wood fuel (or an alternative fuel)
- Better heat management within your evaporator
- Process your product as few times as necessary to avoid reheating it

Minimize Sap Needing to be Boiled

The simplest and lowest-cost way to reduce the amount of sap you need to boil is to throw away ice that has been collected in your pails or holding tanks. This ice is extremely low brix and not worth boiling. We routinely employ this method during the first half of the season when Ice is more prevalent and have measured increases in brix levels from 1 - 2 brix to 2 – 3 brix in the residual sap (depending on the amount of ice discarded).

Even an increase from 1 to 2 brix is a reduction of 50% of the water that you need to boil off. An increase from 2 to 3 brix produces a 33% reduction in volume of sap. Although this method works best at the start of the season when sap is likely to freeze overnight, you can also cease boiling when the brix level in the sap you are collecting falls below 1 brix at the end of the season.

Producers with over 100 taps can usually cost-justify the use of reverse osmosis (RO) to significantly increase brix levels in their sap. The electricity consumed to power the pump used to move sap thru the RO becomes a Scope 2 emissions source that also must be accounted for. But this is far preferable to generating unnecessary emissions by boiling more than you otherwise need to. The opportunity to use RO to reduce sap volume by over 75% is a significant benefit for producers desiring to become net-zero. Some producers use RO extensively to remove over 80 – 90% of the water from their sap, although there is some debate over the quality of the syrup flavour when such high-density concentrates are produced (many traditionalists assert that the maple flavour in the syrup is best developed via boiling because it provides more time for the amino acids in the sap to react with its sugar, causing it to brown and develop its maple flavour).

From a carbon-neutral perspective, the extent of RO benefit to be exploited is up to the producer and their willingness to improve their heat management efficiency. The table below compares these two strategies (you can use the GHG calculation spreadsheet to tune the Brix parameters to better suit your situation):

With Reverse Osmosis			Without Reverse Osmosis		
Input Brix Level	2		Input Brix Level	2	
Output Brix Level	8		Output Brix Level	3	
Sap Reduction Factor	75%	Benefit from RO	Sap Reduction Factor	33%	Benefit from Ice Removal
Input Brix Level at start of boiling	8		Input Brix Level at start of boiling	3	
Syrup Brix Target	67		Syrup Brix Target	67	
Amount to Boil	22%	of original volume of sap	Amount to Boil	64%	of original volume of sap

From a heat mitigation perspective, even a 33% reduction in sap volume is significant. Here is an example that shows how it could enable the same 2,800 tap producer evaporator that is only 50% efficient achieve the same 22 cord of wood budget as using an evaporator that is 75% efficient.

Sequestration per Hectare			4,886	Kg CO2 / yr	**Séquestration par Hectare**
Sugar Bush Size			14	Hectares	**Grandeur d'érablierie**
Potential # Taps Per Hectare			300		**Entailles par Hectare**
Total Taps			4,200		**Entailles Totale**
Expected Syrup Yield per Tap			1	L	**Montant de Sirop Anticipée par Entaille**
Overall Carbon Budget			68,406	Kg CO2 / yr	**Budget de Carbone en Gros**
Allocated to Scope 1			95%	64,986	**Allocation pour Portées 1**
Allocated to Scope 2			3%	2,052	**Allocation pour Portées 2**
Allocated to Scope 3			2%	1,368	**Allocation pour Portées 3**
				68,406	
Carbon Budget for Boiling					**Budget de Carbonne pour Ebullition**
Wood Fuel Conversion Factor			118	KG CO2 / M BTU	*Conversion pour BTU de Bois*
BTU Budget			550	M BTU	**Budget en Millions de BTU**
Operational Data					**Les Dons d'Exploitation**
Input Brix			2.50	Brix	Brix de Sève aux Commencement
Sap to Syrup Ratio pre-RO			34.88		Rapport de Sève à Sirop avant OI
Reverse Osmosis (RO) Reduction of Sap			33%		Reduction par Osmos Inversée (OI)
Input Sap Volume			146,496	L	Volume de Sève aux Commencement
Post RO Volume			98,152	L	Volume apres OI
BTU To Evaporate 1 L			2531	BTU	BTU Necessaire pour évaporer 1 L de l'eau
M BTU Required Assuming Perfect Efficiency			248.42	M BTU	M BTU Necessaire Avec Une Efficaise Parfait
BTU Capacity of Wood Used			22.84	M BTU	BTU Potential dans le Bois Utiliser
Evaporator Efficiency Scenarios	50%		75%		**Scenarios d'efficacité**
M BTU Required	496.85		331.23		MBTU Necessaire
Fits Into Carbon Budget	Yes / Oui		Yes / Oui		Assez de place dans budget?
Fuel Budget					**Budget de Carburant**
Wood	21.8	Cords / Cordons	14.5		Bois
Propane	20,964	L	13,976		Propane
Fuel Oil	12,563	L	8,375		Huille

If you use reverse osmosis to reduce the quantity of sap being boiled, your carbon budget will have less sensitivity to efficiency of heat management. Some producers in the several-thousand tap category are moving to increasingly higher levels of RO (as high as 90% water removal) and using smaller evaporators to boil the smaller quantity of remaining sap concentrate.

The good news is that reducing emissions can be achieved via a combination of minimizing the sap to be boiled and improving heat efficiency. Here is an example carbon budget calculation for the same producer that shows that a 75% reduction in sap plus a 75% efficient evaporator enables the same volume of sap to be boiled with less than 6 cords of wood.

Sequestration per Hectare			4,886	Kg CO2 / yr	**Séquestration par Hectare**
Sugar Bush Size			14	Hectares	**Grandeur d'érablierie**
Potential # Taps Per Hectare			300		**Entailles par Hectare**
Total Taps			4,200		**Entailles Totale**
Expected Syrup Yield per Tap			1	L	**Montant de Sirop Anticipée par Entaille**
Overall Carbon Budget			68,406	Kg CO2 / yr	**Budget de Carbone en Gros**
Allocated to Scope 1			95%	64,986	**Allocation pour Portées 1**
Allocated to Scope 2			3%	2,052	**Allocation pour Portées 2**
Allocated to Scope 3			2%	1,368	**Allocation pour Portées 3**
				68,406	
Carbon Budget for Boiling					**Budget de Carbonne pour Ebullition**
Wood Fuel Conversion Factor			118	KG CO2 / M BTU	*Conversion pour BTU de Bois*
BTU Budget			550	M BTU	**Budget en Millions de BTU**
Operational Data					**Les Dons d'Exploitation**
Input Brix			2.50	Brix	Brix de Sève aux Commencement
Sap to Syrup Ratio pre-RO			34.88		Rapport de Sève à Sirop avant OI
Reverse Osmosis (RO) Reduction of Sap			75%		Reduction par Osmos Inversée (OI)
Input Sap Volume			146,496	L	Volume de Sève aux Commencement
Post RO Volume			36,624	L	Volume apres OI
BTU To Evaporate 1 L			2531	BTU	BTU Necessaire pour évaporer 1 L de l'eau
M BTU Required Assuming Perfect Efficiency			92.70	M BTU	M BTU Necessaire Avec Une Efficaise Parfait
BTU Capacity of Wood Used			22.84	M BTU	BTU Potential dans le Bois Utiliser
Evaporator Efficiency Scenarios	50%		75%		**Scenarios d'efficacité**
M BTU Required	185.39		123.59		MBTU Necessaire
Fits Into Carbon Budget	Yes / Oui		Yes / Oui		Assez de place dans budget?
Fuel Budget					**Budget de Carburant**
Wood	8.1	Cords / Cordons	5.4		Bois
Propane	7,822	L	5,215		Propane
Fuel Oil	4,688	L	3,125		Huille

If you prefer not to use an RO, you need to focus on heat efficiency. Alternatively, if you choose to use an RO you may not need to implement all the recommendations for heat management presented in this paper.

Use Climate-Friendly Fuel

Trees sequester CO2 when they grow and release it when they die and decompose. However, since 20 – 25% of a maple tree's carbon is in its roots, that part of the tree does not release CO2 as it decays because it remains buried in the soil. In other words, a tree is a natural -25% carbon sink over its lifetime. Although the sugar maple has a potential life of up to 300 years, 80 – 100 is more typical. Factors such as pollution, insects and climate change can degrade tree lifetimes.

A mature tree can capture well over a ton of CO_2, so if our goal is to be climate-friendly we do not want to accelerate the release of that carbon by burning it faster than the tree would otherwise store and release over its normal lifetime.

If you use wood as the fuel for your evaporator, burning it converts the stored carbon into CO_2. You can avoid unnecessary CO_2 emissions by using only wood from dead and fallen trees, as well from the culling operations in your sugarbush, or wood waste obtained from sawmills. These are trees that will no longer be sequestering carbon and have, or are about to, enter a phase of CO_2 release through decay. Another option for wood-fired evaporators is to burn wood chips or pellets that are sourced from bio-energy producers. These pellets are certified to have been manufactured from wood waste from sawmills. By preserving the healthy trees who are still sequestering carbon, we do not subtract from what nature is already doing to sequester CO_2.

However, this is an approach to being carbon neutral over a cycle that is hundred years of more (i.e., the lifetime of a tree). We can do better by being carbon neutral within an annual cycle of maple syrup production.

- Another way to look at this is that the trees have in our sugar bush generate an annual carbon budget for us to try to operate within. In doing so, we maintain a net-zero footprint for our operations on an annual basis regardless of the fuel source.
- If we also source wood waste as fuel from a sawmill, or only use wood from fallen trees, we are not adding to the loss of sequestration in our forests caused by the operation of others, or by nature. The problem of forest loss may still occur, that is beyond our control, but at least we are no longer a part of that problem on the activities that we do have control over.

Consequently, we do not take the approach of counting as a benefit all the carbon already captured in our maple trees in our net-zero equation, nor do we penalize the use of cut trees as firewood in our GHG calculations – rather we focus on how we are affecting our own carbon footprint on an annual basis.

Using aged firewood also reduces the quantity of wood required since you do not need to boil off the moisture in the firewood along with the water in your sap (the technical term for this is enthalpy of vaporization). A condensing boiler could capture the heat lost via water vapour, but you still would be vaporizing water in the wood that you don't need to.

- The moisture level in fresh cut wood[2] can be as high as 60% depending on the type of tree it came from, but a more typical level is 50% for most woods burned within one year of being cut. Wood with 50% moisture has a max heating value of approx. 2,136 BTU/kg.
- Cutting your fuelwood even a year in advance will increase its heating value (decreasing your wood consumption) by 30% and reduce your CO_2 emissions by the same amount. Wood with 20% moisture has a max heating value of approx. 2,818 BTU/kg, so basically every 1% decrease in moisture will increase heat value by 1%.
- Ideally the moisture level in firewood should be below 20% which can be accomplished in most cases by splitting and aging your firewood for 2 years before using it.
- Wood pellets typically have been kiln-dried and have less than 10% moisture content. This has a max heating value of 3682 BTU/kg.

Not all the carbon sequestered in wood is released during combustion. We will discuss combustion efficiency in more detail, but perfect combustion efficiency is rarely achieved, so even burnt wood still has some sequestered carbon remaining in its ashes, soot, and coals.

If you use oil or diesel as your fuel, consider switching to propane as burning propane emits 20% - 50% less CO_2 compared to heavier fossil fuels such as fuel oil or diesel (US Energy Administration). The actual difference depends on the relative efficiency of the furnace used (i.e., an efficient propane furnace might produce 50% fewer CO_2 emissions than an older inefficient oil furnace), however, even on the most efficient comparable basis, propane is slightly cleaner than fuel oil.

- According to a study done by Cornell University (available on our website) a cord of hardwood burned in a boiler that is only 50% efficient offers the same BTU as 375 L of fuel oil burned in a 75% efficient boiler (238 L for softwood).
- However, 375 L of fuel oil emits 1,032 Kg of CO_2 while a cord of hardwood emits nearly 3x as much (2,919 kg of CO_2) when burned. So even an equally efficient wood-fired evaporator is not as climate friendly as an oil-fired evaporator if we ignore the upstream emissions from fossil fuel extraction (which are far more significant for oil than for forestry because over half of fuel oil in Canada is sourced from the tar sands).
- According to a study done by the US Congress, total lifecycle emissions for Canadian oil are approximately double their combustion emissions. So, it is possible that an equally efficient wood fueled evaporator can have the same lifecycle emissions as an oil fueled evaporator if we factor in energy extraction emissions per Scope 2 guidelines.

In summary, regardless of the fuel source, the efficiency of heating is the next most important consideration after you have minimized the amount of sap you need to boil. There are two levels to understanding heat efficiency:

- the efficiency of combustion within the evaporator and
- the effectiveness of the evaporator in using the heat generated by that combustion to boil sap.

We have found several keys to better heat management, and will discuss each of these in turn:

1. Don't overheat more than you need to maintain a continuous boil
2. Achieve Secondary Combustion by supplying more air
3. Use your heat effectively
4. Maintain a continuous heat level
5. Maximize the use of the heat that you have generated.

Don't Overheat Your Boil

It is a fact of physics that sap (which is mostly water) boils at 212' F (100'C) at atmospheric pressure at sea level. Everyone knows this but few realize that heat applied above this temperature is mostly wasted. It is not possible to heat a liquid beyond its boiling temperature (unless you also increase pressure which does not happen in most commercial evaporators), and sap only boils at a marginal higher temperature as the water to sugar ratio changes. Even when you reach sugaring, or candy temperatures, you do not need to exceed 220 – 240' F (depending on your product objective).

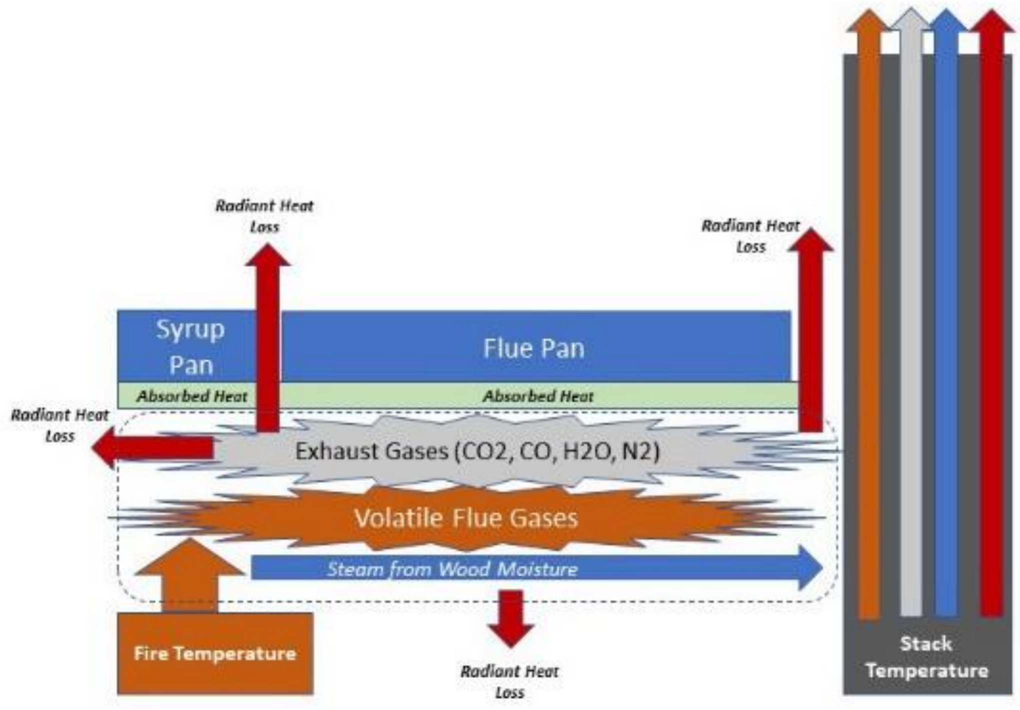
If you measure the temperature of the boil in your flue pan, you will see that boiling starts 10-15' below 212' F (depending on barometric conditions) and reaches a rolling, violent, boil as it reaches 212' F. Although sap may boil faster at a higher temperature in a perfectly efficient

[2] Note that this is NOT the same moisture percentage used in the sequestration calculation. Moisture in that calculation is as a % of the green weight of the wood, the moisture content of firewood is calculated based as a % of the dry weight of the wood.

boiler, heat can only be absorbed at a constant rate once the sap has started to boil – any excess heat beyond that rate of absorption is wasted by the evaporator.

To make matters worse, if you crank up the heat in your firebox it is likely that you are relying only on primary combustion to heat your boil and are missing out on the benefit of exploiting both primary & secondary combustion of your fuel. We will examine this in more detail.

- There is a difference between the heat of your firebox and the stack temperature measured in your chimney. The temperature in the firebox needs to be 550'F to ensure combustion since this is the ignition temperature of wood. Some of this heat is absorbed to vaporize the moisture in the wood (producing steam) and then absorbed via the evaporator before it is exhausted (partially into the boil also lost via radiation). The heat that is not consumed by absorption or lost by radiation is measured in the stack temperature as illustrated below.



Stack Temp = Fire Temp – (Absorbed Heat – Radiant Heat Loss)

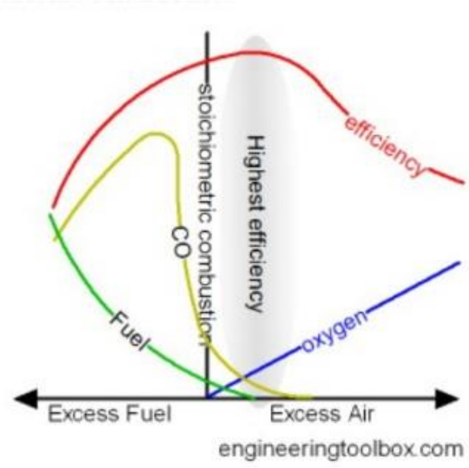
- The first law of thermal dynamics says that energy in must be balanced with energy consumed & energy lost, so the difference between the firebox temperature and the stack temperature gives you an indication of how much has been absorbed into the pans via convection (as well as lost via radiation before it reaches the chimney). The steam produced from wood moisture is still heat available to the pans but is not an efficient use of fuel.
- Also, the higher the heat in the fire, the more likely that hot flue gases will escape unburned (resulting in wasted heat and fuel). Flue gases are volatile gases produced during combustion that have not yet released all their heat until they are fully combusted into exhaust gases. Approx. 50 – 60% of the heat available from burning wood occurs from combusting these volatile gases. This means that if you can achieve secondary combustion, you can gain another 550' – 900' F of heat from these gases without adding any more firewood!
- Exhaust gases (primarily CO_2, CO, and steam) are also hot gases available to the pans but have no more thermal energy to contribute to further combustion. It is the heat of stack gases that are measured by stack temperature which consists of both flue and exhaust gas (to varying degrees depending on combustion efficiency).
- The diagram illustrates steam produced via combustion (as an exhaust gas) as well as from the vaporization of wood moisture. Steam from combustion is unavoidable and a good use of fuel, while steam from moisture is controllable and is a waste of fuel.
- Radiant heat loss occurs due to insufficient insulation of the firebox and arch, as well as via the metal in the pans, arch, and firebox. Any gaps between the pans or between the pan and the arch will also result in significant radiant loss into the air, as well as creating an escape route for stack gases.
- Ideally, you do not want to lose flue gases along with exhaust gases. However, as you crank up the heat in the firebox, both types of gas expand (since pressure cannot increase enough to maintain the volume of these gases with an open chimney flue) and more flue gas escapes via the chimney before it can be fully combusted.
- Some producers will assert that maintaining a very high temperature ensures a rapid convection from the hot air in the firebox into the boiling sap, thereby reducing boiling time.
  - This is true during the initial period when you start the fire until the instant that a boil is achieved. Heat is transferred via convection only by the difference in temperature within the sap, so as temperature is increased the increasing heat is absorbed into the sap until it boils.
  - However, once a full boil is achieved the sap is as hot as it is going to get, convection can proceed no faster than the rate that heat is consumed in the boil – i.e., the rate of convection is governed primarily by demand for, and not supply of, heat after boiling starts to occur.
  - The rate of excitation of the water molecules in the boil is only one of the ways in which heat is consumed in the evaporator. This will increase with higher temperature, speeding the boil, but as there are other radiant losses of heat occurring, not all the increased heat from the fire is used to produce a faster boil. Further, if you increase heat without sufficiently increasing air flow, the evaporator may suffer from incomplete combustion (which we will discuss in more detail) and a higher volume of valuable flue gases will escape unused.

Achieve Secondary Combustion by Supplying More Air

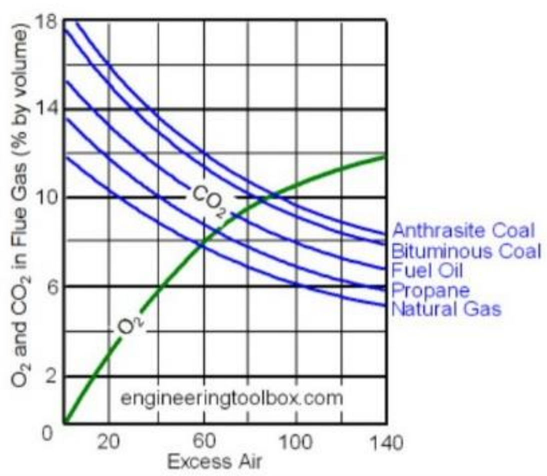
Depending on the configuration of the evaporator, it may be necessary to run the evaporator with a firebox at a higher temperature than 550' F to optimize its combustion efficiency. Let's examine combustion efficiency in a bit more detail:

- During combustion, hydrogen and carbon are oxidized by the supply of fresh air (which is 21% oxygen, 78% nitrogen and 1% other gases).
- If air flow is insufficient, the flue gases produced during combustion will not be fully oxidized into the exhaust gasses of H_2O (steam) and CO_2. Efficient combustion (stoichiometric combustion) occurs when there is sufficient oxygen supplied to enable full combustion of flue gases. As long as the temperature of the fire is at least 550'F, it is more important to increase air flow than temperature to enable full combustion.

- In practice, excess oxygen is necessary to avoid producing carbon monoxide (CO) instead of CO2 as an exhaust gas. Carbon monoxide is not only dangerous but the combustion of carbon into CO releases 1/3 the heat compared to when it is combusted into CO2. So, producing CO instead of CO2 is a significant waste of fuel. The level of CO in exhaust gas increases as combustion efficiency increases up to just before the point of stoichiometric combustion and then falls as excess air is supplied on more CO2 is produced. This is illustrated in the chart below.



- As illustrated by the red line on the graph above, combustion efficiency continues to rise as excess air is supplied past the point of stoichiometric combustion, however, if too much excess air is supplied combustion efficiency drops off due to the cooling effect from that air (more specifically, Nitrogen causes this cooling effect because there is 3x as much Nitrogen as Oxygen in air and it is inert during combustion). For example, as a rule of thumb, in a natural gas or propane boiler efficiency is decreased by 1% for each 15% increase in excess air supply beyond the point of stoichiometric combustion.
- The amount of CO2 in the exhaust gas is a good way to measure of combustion efficiency. The chart below shows the effect of adding excess air past the point of stoichiometric combustion reduces efficiency for all carbon fuels. Wood is not illustrated on the graph, but as previously discussed, the moisture level in wood has a significant effect on combustion efficiency because of the heat lost in vaporization of that moisture, so there would be a different curve on the graph for each moisture level. For wood, 12% extra air by volume in the exhaust gas produces the maximum in combustion efficiency.



- Increasing the temperature in the firebox will warm the excess air and make it easier to maintain efficient and safe combustion. However, too much temperature will also increase pressure of the flue gases (which expand when heated) within the arch and cause them to be evacuated up your chimney faster. For example, in a natural gas or propane boiler efficiency is decreased by 1% for each 40’ F increase in temperature beyond the point of stoichiometric combustion.
- So, efficient combustion is a balancing act involving air flow, pressure, and temperature. Operating at a higher temperature than necessary increases the sensitivity of efficient combustion to air flow and pressure. This is true when combusting any fuel, including wood. The more you increase the heat from primary combustion, the less heat you can generate from secondary combustion of the more rapidly escaping flue gases.
- In the extreme, if you are relying on primary combustion to drive the temperature up in your evaporator you may be consuming up to twice the firewood than you need to generate the same amount of heat.
- The configuration of the evaporator is also an important factor as it is possible to create secondary combustion chambers for burning flue gases within its arch. We will discuss this in more detail under improving heat management.

It is important to reduce the amount of creosol and soot generated during the burn to reduce the tendency of the soot to insulate heat under your pans. Soot is incompletely burned fuel – an indication of incomplete combustion of creosol (which itself is caused by condensation of volatile gases during combustion). Creosol is highly flammable and can be explosive. An explosion of creosol can lift a flue pan full of sap several inches off the evaporator!

Soot is best avoided by optimizing the mix of temperature and air flow, not only by cranking up the heat in the fire.

- Burning wood with the bark still on it will generate more creosol and soot than if you strip the bark off before burning the wood.
- Most wood-fired evaporators require a stack temperature of 450 - 475’F to assure good combustion with minimal soot buildup.
- If the stack temperature is below 450’ F, it is important to ensure excess air flow to optimize combustion to minimize soot build-up. This can be accomplished by adding an air fan and manifold to the firebox in the arch of the evaporator. However too high an air flow will result in a drop of efficiency due to loss of unburned gases during combustion. Ideally the air flow should be the equivalent of 0.05 inches of equivalent water pressure (as measured by a Magnehelic pressure gauge).
- If the stack temperature is below 325’ F, it may be necessary to also add a chimney fan (forced draft) to avoid buildup of soot in the chimney. Unburned flue gas and water vapour will condense around 270’ F, causing creosol to form as the water evaporates. Burning dryer wood reduces the amount of water vapour that can cause the flue gas to condense.
- In larger operations where boiling occurs on an 18 - 24 hour / day basis, it is also important to periodically wash the soot off the underside of the pans to avoid soot acting as insulation, inhibiting convection into the pan.

Most maple syrup producers do not need to fully optimize combustion to become net-zero, however unless you like chopping wood, understanding the mechanics of efficient combustion is helpful in avoiding the unnecessary use of fuel (and its carbon emissions).

Use Your Heat Effectively

Combustion efficiency is just part of overall boiling effectiveness because a maple syrup evaporator is not a perfect thermodynamic system. How effectively we use the heat produced from combustion is just as important when trying to improve the overall efficiency of boiling sap into syrup. The ultimate thermal efficiency is the ratio of fuel input to the amount of syrup produced.

Many old wood-fired evaporators are at best 20% efficient and more modern ones are typically less than 50% (we will discuss how to improve efficiency in the section on heat management). Oil-fired evaporators can be more efficient, and as of the time of writing, the best achieves 83.5% efficiency.

- Insulating your arch and improving your air flow will enable you to work safely and effectively at a lower temperature, consuming less fuel (wood, gas, or fuel oil) by benefiting from secondary combustion, and producing fewer emissions.
    - Ensuring there is adequate fresh air intake into the evaporator is essential to ensuring that all the flue gases are burned (maximizing heat from them) before they go up the chimney of the arch.
    - Since we do not want cold air to cool these gases, it is important for this air intake to occur via the firebox so that the air intake can be heated. One approach is to cut small holes at the back of the firebox, or to add a forced air manifold into the firebox, to admit excess warm air.
    - A draft control on the chimney prevents changes in barometric pressure or wind from sucking the flue gases out of your evaporator before they are fully burned as well as losing the heat available from exhaust gases before they are absorbed into your pans. It will enable you to maintain a continuous pressure in your chimney regardless of barometric changes due to wind or atmospheric pressure.
- The surface area and depth of sap being boiled, the relative humidity of the air above the evaporator, as well as the rate of entry of colder sap into the boil, largely determine the demand for heat (assuming no changes in atmospheric pressure).
    - Increased surface area (enabling more water molecules to be excited by heat) is why most evaporators use folded flues in the flue pan (i.e., raised or dropped flues). If you are using a flat flue pan, consider switching to a raised flue pan to double the surface area that is exposed to heat.
    - Limiting the depth of sap reduces the frequency that heat-excited water molecules lose energy by colliding with less excited ones prior to escaping (evaporating) into the air as steam. This allows more of them to escape during the boil.
    - Evacuation of steam to reduce humidity within the sugar shack also speeds up boiling since it enables more water molecules to escape into the air, instead of bouncing off the molecules in the water vapour immediately above the evaporator and back into the sap. Many sugar shacks have roof vents that can be opened to ensure that humidity is evacuated. Another method is to install a fan that blows less humid, filtered air across the top of your evaporator.
    - Pre-heating sap that is admitted gradually into the evaporator mediates temperature differences that otherwise requires additional heat to raise cold sap to a boiling temperature. Re-using the waste heat from steam produced by the boil is an excellent way to pre-heat sap. Using a flue pan that has multiple channels in it also mediates the effect of colder sap cooling the boil.

The easiest way to monitor your evaporator's temperature is to install a thermometer on the chimney of your arch.

- In our operation, we try to maintain a chimney temperature in the range of 325 - 400'F which we have found is enough to help us ride out the temperature dips when we add wood while avoiding using more heat than needed for efficient combustion.
- A stack temperature of 400' F in a well-insulated arch means that during a boil (which does not occur below 212' F), our fire temperature is at least 550' F from primary combustion plus another 550' F from secondary combustion (for a total of 1100'F input heat), producing at least 300 – 400' F to be consumed by a constant boil allowing for 300 - 400' F for radiant heat loss (that cannot be eliminated).
    - Note that 550 less 400 equals 150 'F which is below the point of boiling, so we know that secondary combustion must be occurring because we can see the sap boil while using as few as 4 sticks of wood. Secondary combustion will generate an additional 550' F, giving us a total of 1100' F of heat (up to 1500' F is possible with the injection of more air).
    - In an evaporator with sufficient air flow, secondary combustion can start to occur in the fire box chamber (although secondary combustion may not be complete). As the hot gases travel along the arch, roughly 200 – 300' F of heat per foot can be consumed into the flue pan of a well-insulated evaporator. So, even if we start with 1100' in the firebox, by the time the hot gases reach the midpoint of a 6-foot flue pan, most of that heat can be consumed via the flue pan and radiant heat loss.
    - The presence of a secondary combustion chamber at the mid-point in the arch enables full completion of secondary combustion which re-establishes heat under the flue pan, ensuring a good boil along the second half of the arch. (We discuss how to implement a secondary combustion chamber in the next section.)
    - Since we do not know the actual amount of radiant heat loss, we conservatively assume that only 50% of supplied heat is consumed in the boil. Calculation of radiant heat loss as the amount of unaccounted heat absorption from boiling a known quantity of sap is difficult since an evaporator is a continuous process in which cold sap enters as the sap is boiled down (requiring solution of a differential equation using approximate parameters). In practice, probably more than half of the heat is consumed in the boil since our arch is well insulated.
    - Note that we do not need to increase the fire temperature much beyond the point of initial ignition to reach this level of efficiency because we are exploiting the additional benefit from secondary combustion both in the firebox and in the secondary combustion chamber of our arch. This requires more air, not more wood.
- We also maintain an air flow of 0.05 inches of water pressure to minimize loss of flue gases and burn mostly wood without bark to reduce soot buildup.
- Burning a mix of hardwood with softwood also reduces soot buildup as softwood is more prone to produce soot (and CO_2) than hardwood.

Remember that **any chimney temperature above the minimum needed for efficient combustion is wasted heat** and waste heat means wasted fuel as well as unnecessary carbon emission. Paradoxically, if you obtain a high combustion efficiency, you will produce more CO_2 per minute compared to a lower level of efficiency, because CO_2 and H_2O are the natural by-products of combustion. However, your combustion will also produce more heat from the same amount of fuel, thereby burning less fuel overall to boil your sap. The less fuel used, the less CO_2 emissions you will have overall.

In summary, at the level of combustion efficiency, your goal is to maximize combustion of your fuel source (which can be measured by increased CO_2 emissions from the combustion process). Simultaneously, at the level of evaporator efficiency, your goal is to not generate more heat than you need to achieve secondary combustion and to use the heat from both primary and secondary combustion as optimally as possible so to minimize the amount of fuel consumed (thereby minimizing your CO_2 footprint). While this may sound contradictory, is inevitable that you will need to burn fuel to boil sap so you may as well as burn it as well as you can to maximize heat produced from it and then use that precious heat as effectively as you can.

Maintain a Continuous Heat

Up until now we have discussed the mechanics of combustion of wood already in the firebox. As this wood burns down, you need to replace it and whenever you open the fire door in your evaporator to toss in more wood, the temperature inside your evaporator plummets as cold air also rushes in, which in turn can cause a vigorous boil to be lost until the heat builds back up.

- Although maintaining a higher temperature under your pans helps in absorbing this cold air rushing in, it does not mean that you need to maintain solder-melting temperatures to withstand those dips in temperature. In many cases, the temperature under your pans has already dropped by the time you realize that you need to add more fuel – so maintaining higher temperatures before that point offers no benefit by the time that the fire door is opened to add fuel.
- You are wasting heat in every minute that your fire doors are closed if your boil is above the minimum temperature necessary to maintain efficient combustion. Even if you add fuel every 10 - 15 min, your doors are closed more than they are opened. Better to keep your boil temperature at a moderate level so that you do not waste that heat up your chimney.

Here are a few more efficient strategies for maintaining continuous heat than overheating your boil between refueling intervals.

- Maintaining a lower depth in your pans enables you to recover from lost heat faster since there is less volume of sap to reheat.
- Using a mix of both hard and soft wood to fuel your fire reduces the time needed to recover the temperature of the boil after reloading. Softwood burns faster and hotter than hardwood and will reheat the boil faster while heat from the longer-lasting hardwood is being built up. Hardwood burns longer and its heat will replace the softwood heat as it dies off, reducing the frequency that you need to refuel. The optimal mix will likely vary based on the dynamics of each evaporator and mix of wood available to the producer.
    - In our case we use a mix of maple, oak, birch and white cedar and are still experimenting on the optimal mix of each.
    - Many Quebec maple syrup producers use a 30% softwood 70% hardwood mix, so that is the point of departure in our own experimentation.
- The size of your firewood and the frequency that you load it is also important in maintaining a continuous heat level. If your firewood is too large, it takes longer to start to burn. Although it may seem counter-intuitive, it is easier to maintain a continuous heat level if you load smaller quantities of wood more often than if you wait for the fire to die down before adding more wood. Some evaporators have a temperature gauge that helps them decide when to add more fuel, however, we have found that you can also determine this from watching the intensity of the boil in your flue pan.
- Overstuffing the firebox with wood is counter-productive since air is the other active ingredient necessary for efficient combustion. In loading the firebox, it is important to ensure that there is enough room left in the firebox to enable the supply of fresh air to feed the fire as well as secondary combustion of flue gases.
- Ash management is also essential for maintaining a continuous heat level. Air should flow easily around the wood fuel in the firebox and ash build-up can impede air flow. Managing ash is easily accomplished by ensuring that ashes are removed between boils and, depending on your firebox, using an air manifold with a fan that forces air into the firebox to prevent excessive ash build-up during the boil.
    - A simple technique that can be employed in older evaporators that does not require adding an air manifold is to push the residual coals to the back of the firebox when adding firewood and to leave the ash door slightly open to increase air flow into the burning chamber. This helps in keeping the air grates clear of ashes.
    - In larger operations that boil over extended periods of time, it is necessary to stop the boil to clean out the ash buildup after every 24 – 30 hours of boiling (depending on the composition of your wood mix).
- A couple of techniques for minimizing the time that fire doors are opened are to pre-stage the wood that you plan to load before opening the door (so you don' leave the door open while you trot over to the woodpile to get more wood), and, if your firebox has double doors, opening and reloading only one side at a time (waiting for the heat to build back up on one side before loading the other side).

Improving Heat Management

The configuration of your evaporator's arch and chimney plays a big part in the effective use of heat.

The first step in heat management is to ensure that your chimney is compatible with the size of your evaporator. Correct chimney size will ensure that there is adequate, but not too much, air flow out of your arch.

- The volume of the chimney (diameter times length) should correspond to the BTU capacity of the combustion chamber. If the chimney capacity is too small, pressure will build inside the evaporator causing air to be forced out faster.
- The height of the chimney should be at least 30" above the highest point on the roof of the cabin. This, along with the use of a draft control, will enable a higher pull of air without the risk of backdraft. Many evaporators lose 15% of their efficiency due to inadequate draft control when hot flue gases are literally sucked out of the evaporator.

Improving heat retention inside your evaporator is extremely important:

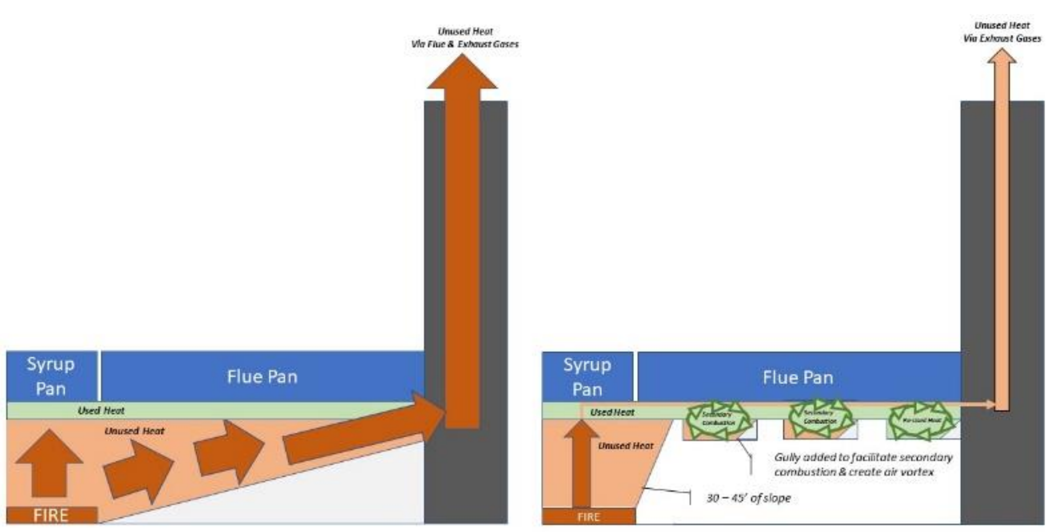
- First step is to eliminate loss of heat via bricking, insulation with ceramic wool, and preventing any heat escape between your arch and the pans, or between the pans.
    - Older evaporators tend to have insufficient (or no) insulation of the fire door. If it is too hot for you to stand in front of your fire door, consider insulating the interior of it with fire brick.
    - Very small producers who do not yet have their evaporator in a sugar shack, should consider enclosing their evaporator to protect it from cooling effect of winds. Although cool air blowing across the top of an evaporator will speed evaporation, cool air hitting the sides of the evaporator will dissipate valuable heat that otherwise would be consumed in the boil.
    - In all evaporators, it is necessary to ensure that fire-brick lines the walls of the arch, ceramic wool lines the base of the arch (less expensive than bricking it), and that the pans sit on insulating pads to prevent heat loss between the edges of the arch and the edge of the pans.
    - In larger evaporators, the application of a ceramic paint such as HL-100 inside the arch can further reduce heat loss.
- Next you should regulate the flow of air through the firebox, along the arch, and up your chimney. Installing an air-flow intake flapper (draft control) on your chimney is especially important as this mitigates the effect of external wind pressure that would otherwise literally suck the heat out of your evaporator on a windy day. Installation of a draft control by itself can improve your efficiency by 15%. You can also install a damper that you can turn to decrease/increase the size of the opening between your arch where it meets the chimney.

To understand how well this is all working for you while you are boiling, we recommend installing an air pressure gauge (Magnehelic / Dwyer analog pressure gauge) to ensure that the air pressure is not too high (meaning that heat is flowing faster out of your evaporator than you want it too.

- In our operation we use a Magnehelic to measure our air flow in the arch.
- Using the Magnehelic we maintain 0.05 Inches of Water Equivalent pressure to ensure adequate air supply to enable secondary combustion. We use this to help us decide when to keep the ash door slightly open or not, or if you are using an air fan to inject air into your firebox, what speed to run the fan at.

The way in which the air flows under your pans from the firebox to the chimney is extremely important. By using ramps and gullies inside your arch, you can compress and expand the air as it flows, creating vortexes of circulating air as well as opportunities for secondary combustion of flue gases, to ensure that you optimize the use of the hot air under your pans before they exit via the chimney.

- This is illustrated conceptually in the following diagram.
  - The Green zone illustrates the amount of hot air that is productively transferred into heating the sap in your pans (shown in Blue). Since only the air in contact with the pans can conduct heat, the green zone extends less than 2 inches below the pans.
  - The Orange zone illustrates the waste heat inside the evaporator. The larger the space below your pans past a couple of inches, the larger the orange zone becomes.
  - The more efficient evaporator on the right greatly reduces the amount of waste heat and creates heat cycles to re-use heat before it is emitted out the chimney.
- As hot air proceeds up the ramp it is compressed, then as it reaches a gully in the path of the arch it expands as it flows into it, creating a circular vortex of air before it is compressed again as it exits towards the chimney.
- If sufficient oxygen is present (via warm air flow from the firebox) the first gully also acts as a secondary combustion chamber ensuring further combustion of the flue gases. In practice it is sufficient to have only one of these chambers for secondary combustion, subsequent ones can be shallower as they serve only to recirculate hot air via a vortex effect. Since the hot gasses are cooling as they travel along the arch, you do not want to create heat sinks within the arch by using deep gullies.
- Regardless of whether you use dropped flue or raised flue pans, the principle at work is to ensure that only the usable heat travels along the length of your arch to the chimney.



Inefficient Evaporator   Efficient Use of Heat

How to optimize the configuration of a wood-fired evaporator has been well-researched by scientists and technicians in the Quebec agricultural colleges.

- There is an active, online, French-speaking community ("LesSucriers.com") that exchange tips and demonstrations of how to retrofit heat management improvements into a wide range of evaporators.
- Goudrelle's videos on Youtube are rich in information for French-language speakers and he can also be employed to improve your evaporator's efficiency on a turn-key basis.
- Mr. Vincent Poisson, a forestry engineer, also produced a handbook for optimizing wood-fired evaporators in Dec 2014 entitled "L'évaporateur au bois" that examines some of these concepts in-depth.
- These experts have demonstrated that it is possible to achieve 70 - 80% efficiency from a wood-fired evaporator and even improve on the efficiency of modern "off-the-shelf" commercial evaporators.

You can calculate your evaporator's efficiency level by calculating the ratio of the theoretical amount of BTU required to boil a quantity of sap to the actual BTU-equivalent of the quantity and type of wood that you used to boil it. In a perfectly efficient evaporator, all the BTU released by burning the wood would precisely match the amount of BTU needed to boil your sap with no loss of heat. In practice it is difficult to exceed 85% efficiency in a wood fired evaporator.

- As a testimony, prior to retrofitting our 20+ year old Waterloo evaporator we were at 13% efficiency. We were losing heat everywhere and were maintaining such high wood fire temperatures that we discoloured the metal on our chimney.
- After implementing the retrofits, we can now boil 2,000 L of sap per face cord of wood which works out to slightly over 80% efficiency for the wood mix that we employ.
- For example, it takes 180 BTU/lb to heat sap from 32' F to 212' F and a further 970 BTU to evaporate it once it has reached that temperature. That works out to 2,531 BTU per L of cold sap. You can look up the BTU produced by different types of wood on several websites (Ontario Woodlot Association, & USDA have tables for various species, as does the North America Maple Syrup Producers Manual).
- In our case, the wood mix we used this year worked out to 7 M BTU per face cord of wood as shown in the table below (our wood was air-dried for a year, so the BTU values are slightly lower than what we could have achieved by drying the wood longer):

Mix		BTU per Cord
50%	Bur Oak	26,200,000
1%	Sugar Maple	24,000,000
10%	White Birch	20,800,000
9%	Yellow Birch	23,600,000
30%	White Cedar	12,200,000
100%	Average	21,204,000
	21,204,000	BTU per Cord
	7,068,000	BTU per face cord

- This year we burned ¾ of a face cord, i.e., used 5.3 M BTU, to boil 1,832 L vs the 2100 L of sap that the same BTU could boil in a perfect evaporator, implying 1800/2100 = 86% efficiency. Our actual efficiency is less because this calculation presumes that we boiled off all the volume of sap entirely, but we only boiled to enough to achieve a syrup density of 67% brix from a starting point of 2 brix. So, our achieved efficiency is closer to (1 – 2/67) x 86% = 83% which is close to the optimal combustion efficiency possible in a wood evaporator.

Reducing The Need to Reheat

It is obvious that reducing the number of times that you need to heat your product as you process it will cut down your heating emissions. So, what are some opportunities in your process to do this?

Many experienced producers have already discovered that it is less work to draw off their syrup at a higher temperature than 219’ F (104’C) and blend it down to the desired brix level for bottling, than it is to have to reheat their product later via a finishing boil. This is also more heat-efficient since the syrup is already close to the desired temperature when you draw off and you do not need to generate heat to get it back to that temperature in a later finishing step. We employ this approach in our operation by blending-in filtered sap, or distilled water, as we reheat the syrup to hot-pack it into bottles.

Some producers are also able to bottle during their draw-off process immediately after filtering their syrup. This allows them to hot-pack their hot syrup as they draw off which is one fewer step requiring re-heat.

In our operation, we are unable to bottle as we draw off due to space constraints in our sugar shack. So hot-packing requires a small amount of propane to be consumed to reheat our product in a subsequent step. Fortunately, the direct emissions from propane are relatively low for this step however this remains a future opportunity area for us to improve on in future.

If you do hot-pack in a separate reheating step and use a double boiler for bottling, remember that you obtain no benefit from having the burner under the water jacket cranked up once the water has started to boil. No amount of heat applied to it will make it heat up the syrup faster.

Example Scope 1 Calculation for Heating

Evaporation in our operation this year required 0.75 face cord of wood to generate 5.3 M BTU while producing GHG emissions of 116.2 Kg CO2 per M BTU, for a total of 616 Kg CO2.

Finishing using propane to reheat the syrup required approx. 10 L of propane producing 1.52 Kg CO2 per L for an added contribution of 15.2 Kg CO2.

Calculating and Minimizing Scope 1 Emissions from Supporting Activities

Emissions from indirect activities will vary by producer and can arise from:

- cutting and splitting the wood used in your evaporator,
- tapping trees,
- hauling your sap to the sugar shack,
- cleaning & washing of pails, buckets, tanks, evaporator, bottles, etc.
- transporting & selling your finished product
- advertising your product

In our operation we eliminate emissions from cutting wood by using electric chain saws, but we still burn gasoline in our wood splitter and ATV used to support tapping and to collect sap. We have mitigated ATV use by focusing our tapping activities closer to the sugar shack and intend to further improve this by purchasing an electric ATV as they become more readily available over the next few years.

As it turns out, the total volume of gasoline used this year in our operation was minimal because of our low wood consumption: approx. 4 L of gas in our wood splitter (which produced enough split wood for several seasons) and another 6 L in our ATV due to a shorter sap harvesting season. At 2.3 Kg CO2 / L of gasoline, this contributed an additional 34.5 Kg CO2 in emissions.

Our second highest source of GHG emissions comes not from heating, or transportation, but from cleaning and washing of buckets. Our farm uses an on-demand hot water heater fueled by propane, which is efficient, but washing nonetheless uses a lot of hot water. Like most producers we wash all our buckets/pails/tanks/etc. at both the start and end of the season and at least once during the season. When we calculated the amount of propane used to heat water for washing, it emitted over twice the CO2 than our consumption of gasoline.

This is not surprising because it is common that once you implement improvements to mitigate your primary emissions, inevitably your emissions from secondary activities become your next major foe. The goal is to make successive improvements every year to continue to mitigate your largest emissions thereby reducing your footprint each year.

In the case of washing-related emissions, we are exploring how we can capture and condense the steam from our evaporator to store hot water that can be re-used for some of these washing activities. We are also migrating our taps from use of pails to gravity-fed lines to reduce the total amount of equipment requiring washing.

We are a small producer, with most of our sales at the farm-gate, so we have minimal indirect emissions from transporting our product to the point-of-sale. We do have a distributor in town who also sells our product, and we mitigate the emissions required to transport our product to them by piggybacking other errands that we would otherwise have to drive to. This enables us to split the cost of our already moderate transportation emissions. Down the road, we plan to purchase an EV pickup truck as they become commercially available.

You can use the volume of fuel consumed on those trips to calculate your CO2 emissions for taking your goods to market. If you track your milage anyway for tax expense purposes, a quick way to do this is to multiply your total milage on those trips by the fuel economy factor of your vehicle (i.e. L / 100 km) to provide you with the total litres of gasoline or diesel consumed. Multiplying that number by 2.3 Kg CO2/L (for regular octane gasoline) will reveal your carbon emissions from that volume of fuel.

Advertising costs and its indirect emissions vary greatly by producer but tend to be minimal. We mitigate this in our operation by using only digital advertising and a single re-useable farm-gate sign. So these are actually Scope 3 emissions for our case. However, if you use print flyers, brochures, etc., you will need to figure out the direct emissions (which are likely to be primarily in transporting paper supplies & advertising to/from your office), bearing in mind that the emissions used by your suppliers to manufacture the paper and ink are also Scope 3 emissions.

Scope 2 Carbon Emissions

According to the GHG Protocol, the international standard for reporting of emissions, your direct use of electricity must be counted as a source of indirect emissions. Maple syrup producers in provinces such as Quebec where virtually all electrical power comes from non-GHG emitting renewable power sources have an obvious advantage.

Fortunately, Ontario has taken significant action in recent years to reduce the GHG emissions created during power generation. According to the Canada Energy Regulator (the latest data available is for 2017), the average GHG intensity in Ontario was 40g CO2 per kWh. This compares unfavourably to 1.2 g/kWh in Quebec and 3.4 g/kWh in Manitoba but much better than 280 g/kWh in New Brunswick. Note the units: these are grams, not kilograms.

If you are a small producer, it may be simple to add up the activities that use electricity and use a direct use estimate to calculate the total kWhr consumption. In our case, for example, we currently use minimal power to recharge the batteries in our electric chain saws and tapping drill as well as to provide light in the sugar shack while boiling. We also use an electric oven to pre-heat our bottles prior to hot-packing our syrup.

For example, if the nameplate on your electric battery charger says it uses 1.2 amps, multiplying by the input voltage of the charger will give you the equivalent in watts. Multiplying those watts by the charge time(s) will provide an estimate of the Watt-hours consumed. E.g. recharging an 80 V DC battery at 1.5 Amps for an hour on a 120 V AC circuit consumes 120 x 1.5 / 1000 = 0.18 kW, which in Ontario indirectly emits 0.18 x 0.04 = 0.007 kg CO2 – pretty minimal. Lighting your sugar shack for 40 hours with two 5W LED light bulb consumes 0.4 kW and emits 0.016 kg CO2 – again minimal.

If you are a large producer, using a variety of pumps and other electrically powered devices, you may already have a separate meter that tracks the electrical consumption of your maple syrup operation.

If neither of these approaches fit your situation, the simplest way to calculate your Scope 2 emissions is to use the total kWhr from your hydro bill in the months in which you produced maple syrup and subtract your average personal electrical use calculated in the months that you do not produce syrup. This will provide a comprehensive, if slightly inaccurate, estimate as it will obviously catch anything that you might miss were you to try to itemize everything.

If your Scope 2 emissions are high, one way to mitigate them is to generate some of your own power from renewable sources such as solar or wind, or from hydrogen fuel cells. Solar power is both free and carbon-free during generation. In our case, down the road as we introduce more electrical tools, we might explore using a solar panel to charge a battery bank (such as a Tesla Wall) from which we could recharge electric saws, ATV, etc.

You also need to account for the lifecycle carbon emissions from your fuel usage. However, the appropriate lifecycle factors are built-into the GHG calculator on our website, so all you need to do is identify the total amount of other fossil fuels consumed.

Scope 3 Considerations

For practical purposes it is currently impossible to compute Scope 3 emissions, until they are disclosed by your suppliers. According to the GHG Protocol, these constitute your “GHG risk exposure”. Even though we cannot calculate them yet, we can identify and rank the risk from them (there is a Scope 3 Risk Assessment tab in the GHG calculator on our website for this) and then mitigate that risk exposure.

Scope 3 risk assessment is done by listing the indirect emissions from the materials and activities in your production of maple syrup and rating them by the extent to which they recur annually and the likelihood that they may have significant carbon emissions. For example (see also the table below):

- Your existing inventory of equipment (evaporator, tanks, pumps, etc.) is a sunk cost from an emissions perspective. Any Scope 3 emissions associated with them when they were manufactured were released in the past and there is nothing that can be done about that. To the extent that you can continue to repair, reuse, and avoid replacing them they do not contribute to your current Scope 3 footprint. When you do replace them, you can amortize their inherent carbon emissions over the lifetime of the equipment, so the annual risk level is low.
- If you sell your maple syrup wholesale by the barrel as a partially finished product to a third party, you also need to count the Scope 3 emissions from their final boil and bottling done in the finishing stage. The annual risk is high because it occurs every year and the re-boiling by the third party is likely to release a high level of carbon emissions.
- The packaging used in your product is likely to be the highest risk and greatest source of Scope 3 emissions since they are largest, annual, recurring, one-time use items in your operation.
    - Eventually, the sellers of bottles will have to disclose the exact carbon footprint of each bottle, but until that occurs, we can estimate it based on various studies.
    - According to a 2010 study by the US Glass Packaging Institute, the industry-wide average CO2 emissions are 1.25 KgCO2 per kg glass manufactured. Since a typical 500 ml bottle used for maple syrup weights 0.415 Kg, this would imply a carbon footprint of just under 1 KgCO2 per litre of maple syrup packaged.
    - We mitigate secondary pollution from plastic by not using single-use plastic bottles or cans, and we offer our customers a refund should they return glass bottles to us. We accept any bottle that has been previously used for maple syrup by any other producer (in good condition) since they can be easily sanitized (more washing!). Although we cannot sell syrup in those bottles, we can re-use them for gifts of syrup to friends and family.
    - Bottlecaps are never reused for sanitary reasons but fortunately are relatively small and not likely to be a large source of Scope 3 emissions due to their small size and weight.
    - The GHG calculator available on our website can help you estimate Scope 3 emissions from the packaging commonly used for maple syrup.

- Lines are reusable from year to year so any Scope 3 emissions from buying new or replacement lines can be amortized over the number of years of use that you expect to get from them. Hence the possibility of inherent carbon emissions is low to medium risk because of their relatively small mass and the fact that you reuse them for several years reduces that risk to low.
- Pails/Buckets/Lids are also reusable from year to year as per Lines and the same reasoning results in a low risk.
- Taps vary depending on whether they are re-used but fortunately are small and hence their manufacture is not likely to be a large source of Scope 3 emissions even when consumed in bulk. Hence, they are a low risk.
- Labels and print advertising may have a higher impact, depending on how they are delivered to you, and the quantity that you order at a time. Ordering a large batch at a time will mitigate transportation emissions by delivering them to you more efficiently. Overall another low risk if you order them in quantity.
- Digital advertising is likely to have extremely low Scope 3 emissions since most of the major advertising websites (Facebook, Google, etc.) already offset entirely the emissions of their data centres.
- If you ship your finished product in high volume to a variety of retail outlets, it is likely that your Scope 3 transportation emissions may be high. If you ship long-distance, these emissions may even be higher than your packaging emissions.

Scope 3 Carbon Emission Risk Analysis / Analyse de Risque d'Emissions de Portée 3			
	Quantity Per Yr / Quantitée Par An	Emission Risk / Risque d'Emissions	Assessed Risk Rating / Risque Evaluée
Upstream Activities /Activités en Amont			
Equipment Purchased (each yr) / Equipement Achetée (chaque année)			
Taps / Chalumeaux	High / Haute	Low / Bas	Medium / Moyen
Lines / Tubulures	Low / Bas	Low / Bas	Low / Bas
Buckets / Seaux	Low / Bas	Low / Bas	Low / Bas
Covers / Couvercles	Low / Bas	Low / Bas	Low / Bas
Tanks / Réservoirs	Low / Bas	Low / Bas	Low / Bas
Filters / Filtres	Low / Bas	Low / Bas	Low / Bas
Extractors, RO / Séperateurs, OI	Low / Bas	Low / Bas	Low / Bas
Cleaning Chemicals / Produits de Nettoyage	Medium / Moyen	Medium / Moyen	Medium / Moyen
Boiling Accessories / Utils d'embouilliage	N/A	Medium / Moyen	N/A
	N/A	N/A	N/A
	N/A	N/A	N/A
Packaging Used / Emballage Utilisée			
Bottles / Bouteilles	High / Haute	High / Haute	High / Haute
Labels / Etiquettes	High / Haute	Low / Bas	Medium / Moyen
Candy & Cream Containers / Boites pour Bonbons	N/A	Low / Bas	N/A
Caps / Bouchons	High / Haute	Low / Bas	Medium / Moyen
Barrels / Barils	N/A	Low / Bas	N/A
	N/A	N/A	N/A
Downstream Activities / Activités en Avale			
Transportation			
Supplies / Provisions	Low / Bas	High / Haute	Medium / Moyen
Shipping of Finished Products /Expedition des produits	Medium / Moyen	High / Haute	High / Haute
Employee Commuting / Voyages quotidien des employés	N/A	High / Haute	N/A
Business-related Travel / Voyages d'Affaires	N/A	High / Haute	N/A
	N/A	N/A	N/A
	N/A	N/A	N/A
Waste Generated / Déchets			N/A
During Operations / Pendant Exploitation	N/A	Medium / Moyen	N/A
End-of-Life Equipment Disposal / Au fin de vie d'euipments	N/A	Medium / Moyen	N/A
	N/A	N/A	N/A

As more companies implement their own net-zero objectives, they mitigate and ultimately eliminate the risk of increasing your Scope 3 footprint. Preferring to favour suppliers who have a published net-zero objective is something you can do to encourage their transition as well as lower your inherited Scope 3 emissions.

As an industry, establishing province-wide bottle return policies for glass bottles would greatly help mitigate Scope 3 emissions for maple syrup producers. In Ontario, regulations require the use of new bottles only when selling maple syrup, but the OMPSA could take an active role in enabling the sale of product in re-used glass bottles as well as promoting the increased use of recycled glass. Establishing regional depots for swapping clean, used bottles of different styles is something else the OMPSA could organize, or alternatively work with the Beer Store to take back and redistribute used bottles to members who choose to participate.

Since the next-best thing to re-using a bottle is to recycle it, more could also be done to ensure that all bottles used for beverages are recycled:

- Glass used for food and beverage containers is 100% recyclable, and, according to the European Container Glass Federation, every 10% increase in recycled content reduces CO2 emissions by 5% during bottle manufacturing for (due to less heat being needed to melt the recycled cullet). Yet, according to a 2019 study in Ontario, less than 30% of glass is recycled via existing blue box programs (compared to over 60% in Quebec and over 90% for alcohol bottles in Ontario).
- There is no reason why maple syrup and other beverage bottles could not be easily recovered and recycled as we do for alcohol in Ontario by simply increasing the range of bottles that can be returned by consumers via the Beer Store. The new producer-responsible regime in Ontario may also introduce other opportunities for OMPSA to partner so that we all reduce our Scope 3 emissions from packaging.

Summary

In summary, sequestration of carbon by the mature trees in your sugar bush establish your total carbon emissions budget that is decremented by your Scope 1 - 3 emissions.

- The amount of sap needing to be boiled will determine the extent to which you will need to pay attention to heat management and combustion efficiency in your evaporator. This drives approx. 90% of your Scope 1 emissions. If you are using reverse osmosis, you can be less efficient in heat management and still be carbon neutral (however, you still have an opportunity to reduce fuel costs and boiling time via greater efficiency).
- If your carbon budget is still positive after subtracting your Scope 1 & 2 emissions, we propose that your sugaring operation can be characterized as "climate friendly" since your direct emissions are offset by C02 sequestration. Well done!!
- If your budget is still positive after also subtracting a reasonable allowance for Scope 3 emissions, your operation is officially "net-zero" in accordance with the international GHG Protocol. Congratulations!!

Our operation is living proof that it is possible for maple syrup producers to achieve net-zero GHG emissions. Achieving this status as an industry is a potential branding opportunity that could be as significant "organic" branding as more consumers are increasingly climate conscious.

Larger producers might be daunted at the prospect of becoming carbon-neutral due to their scale, but they have several advantages that smaller sized producers do not have:

- First, larger producers are more likely to be employing RO to reduce the amount of sap to be heated. This effectively makes their carbon footprint 75 - 83% smaller, or more, than if they were not using RO.
- Secondly, larger evaporators are more likely to be heated with propane instead of wood which is emits less CO2 per BTU generated. Propane evaporators are also more likely to be higher efficiency than older wood-fired evaporators so less remediation may be required to improve heat management.
- Finally, their sugar bushes are 10x the size of a smaller producer which provides them with a 10x larger carbon budget, and hence more "wiggle room" compared to a smaller producer to accommodate a reasonable allowance for Scope 3 emissions.

Even if you are not immediately successful in achieving net-zero, and need to move towards that goal in phases, everyone wins if we all reduce our carbon footprint via successive improvements every year.