BREWING WITH HOPS

PRACTICAL BREWING CONSIDERATIONS

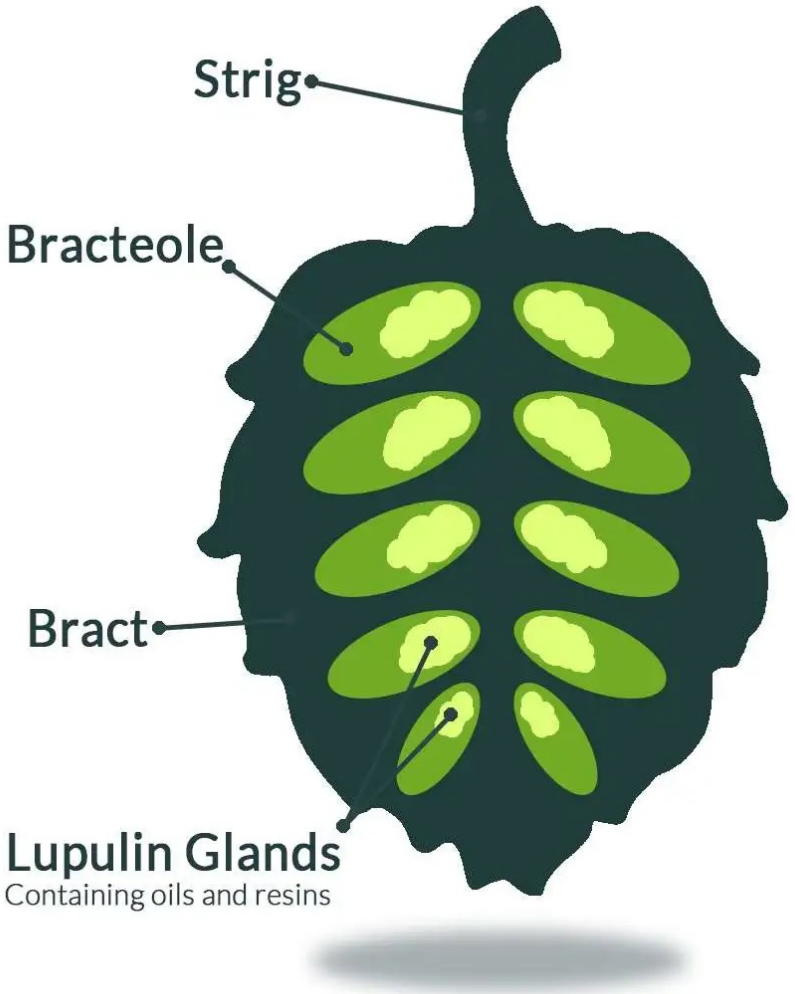
AGENDA

- Quick review of the hop plant and the history of hops in beer
- Growing regions
- Breeding programs and exciting new hop varieties
- Classifying hop varieties for use in beer brewing
- Hop chemistry
- Brewing with hops
  - Hot Side hop additions-mash hopping, 1st wort hopping, kettle hopping and whirlpool hopping
  - Fermentation Dry Hopping
  - Post fermentation dry hopping
  - Using hop products in finished beer

THE HOP PLANT

- Humulus Lupulus
- The plant is called a “bine”, not a “vine”
- Perennial
- Male and female plants. Female plants desired
- Rhizomes used for reproducing, not pollination
- Coils clockwise around twine
- Strung 19-23’ high
- Dwarf varieties are trellised lower
- Bred for disease resistance
- US ~890 plants per acre

THE HOP CONE/ HOP FLOWER

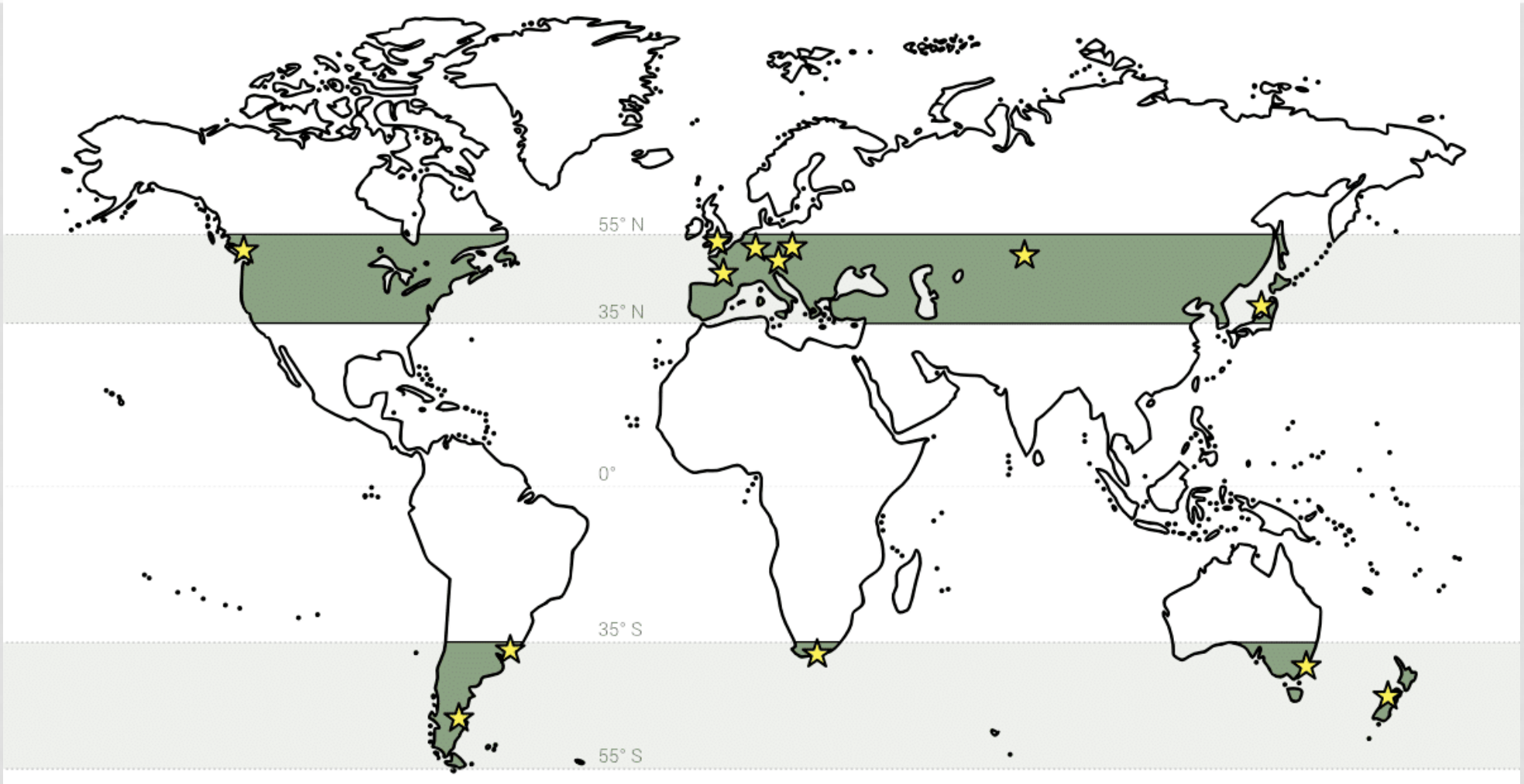


MALE HOP PLANT

GROWING REQUIREMENTS

- 15 hours daylight for 120 days without frost during the growing season
- Winters cold enough (<40°F) to drive the plant into dormancy for 6-8 weeks
- 30°-52°Latitude, 45°-50° latitude is best
- Trellises
- Lack of male plants
- Lack of pests and diseases in area:
  - Hop aphid, spider mite, prionus beetle
  - Downy mildew, powdery mildew, Verticillium wilt, hop stunt viroid, etc
- Terroir: Including soil, weather, slope, direction, location
- Water

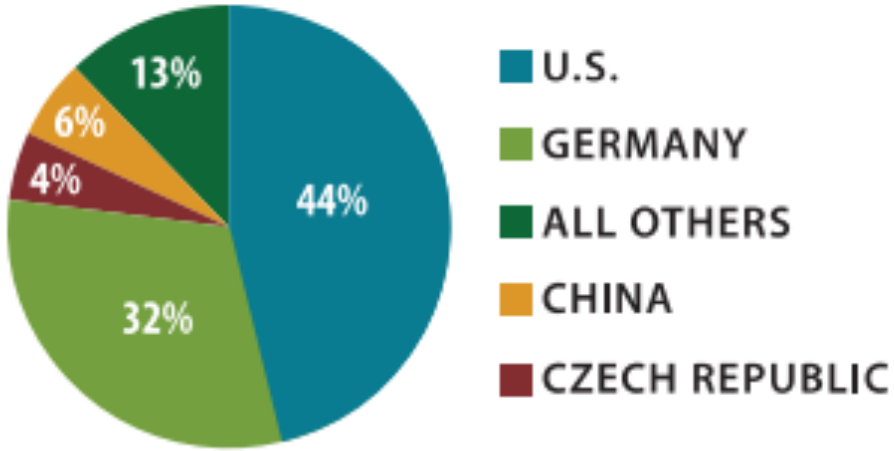
HOP GROWING REGIONS



HOP PRODUCTION IN MAJOR GROWING REGIONS

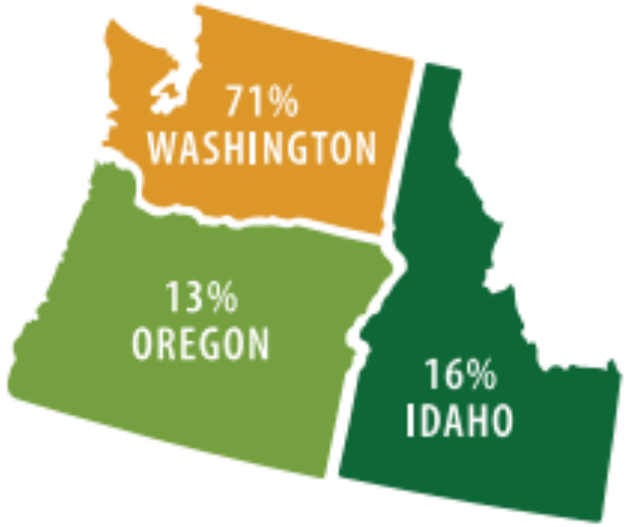
2022 WORLD HOP PRODUCTION

In 2022 the United States provided 44% of the world's hop supply.

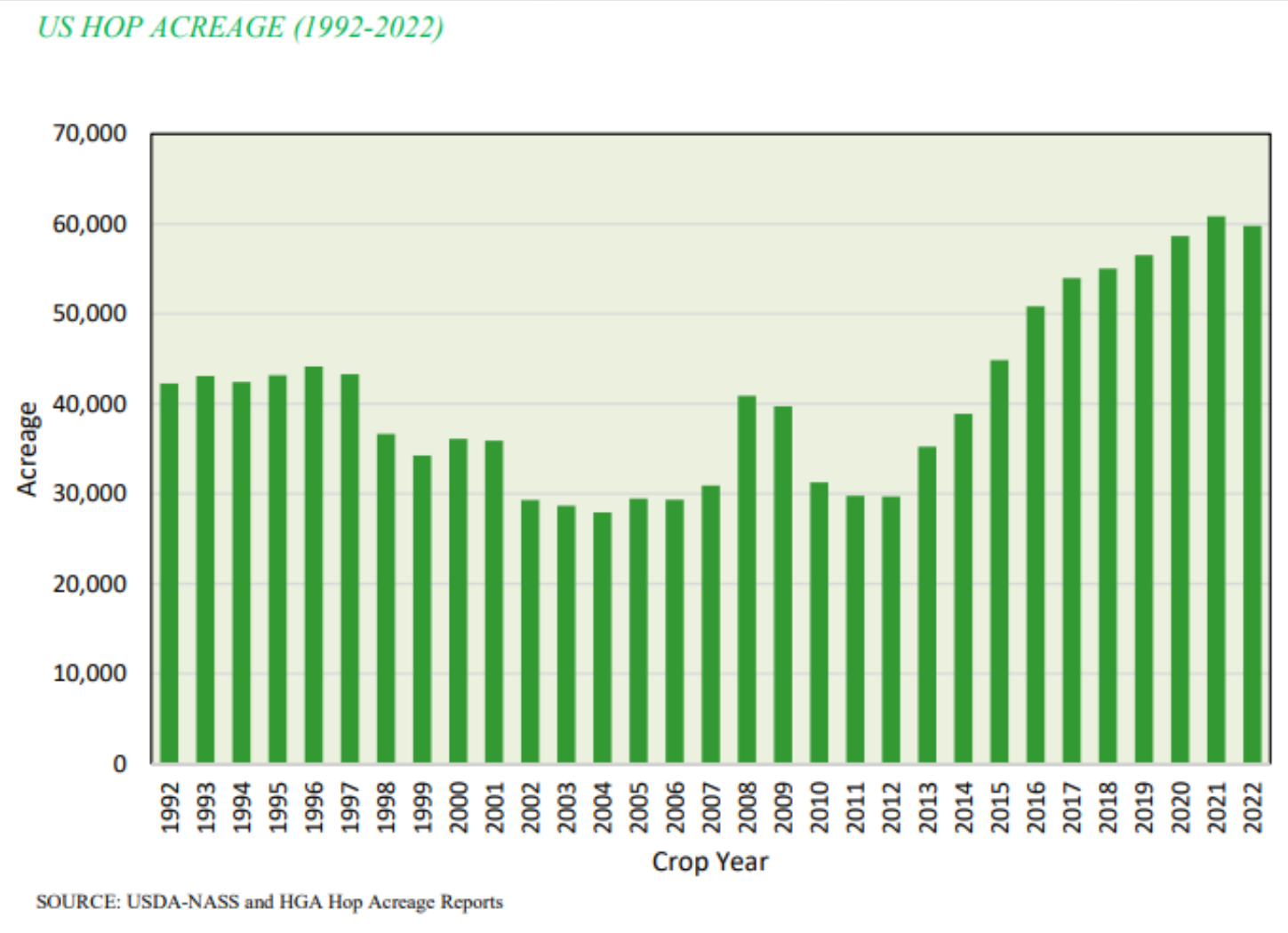


2022 PNW PRODUCTION BY STATE

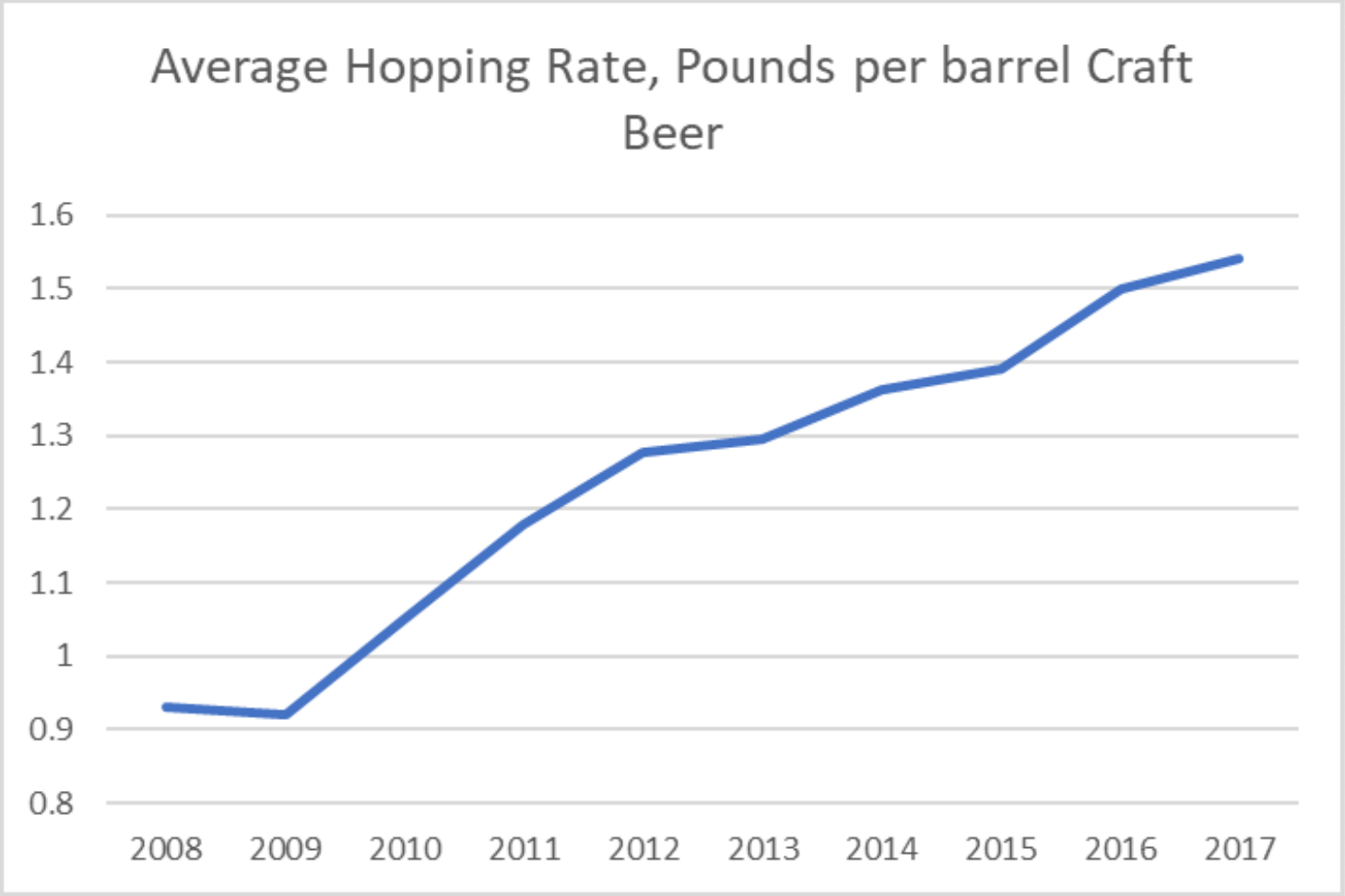
The Pacific Northwest states of Washington, Idaho, and Oregon account for 98% of U.S. hop production.



US HOP ACREAGE OVER 20 YEARS



CRAFT BREWING INDUSTRY HOPPING RATES



HOP BREEDING

- Thought to have started early 1900s Japan
- Public breeders: USDA
  - Varieties: Older hops, Cascade, Centennial, CTZ, Cashmere
  - Large push right now by industry organizations to fund public breeding programs
- Private breeders: Increasing popularity (rare-ness):
  - Varieties: Amarillo, Citra, Mosaic, Equanot, Talus, Lotus, Lemondrop, Azacca, El Dorado
- Lots of biotechnology and DNA markers used
- Hop breeding is a major fuel for craft beer innovation over the past 2 decades

HOP BREEDING AGRONOMIC CONSIDERATIONS

- Yield in bales per acre (1 bale = 200 pounds) or pounds per acre. Good yield is over 2000 pounds per acre
- Disease resistance
- Insect resistance
- Weather tolerance
- Water requirements
- Strength of plant
- Strength of cone
- Ease of harvest
- Picking window (ripening schedule/ harvest optimum)
- Brewers' preference: Alpha acid content, aroma, brewing performance

THE BREEDING PROCESS

- Year 0-1: female and male parents selected and crossed
- Year 2: Seedlings groen in greenhouse evaluated for disease resistance-powdery mildew
- Years 2-4: single hill plots for further screening for disease resistance, maturity, chemistry and aromatics
- Years 5-8: Multi-hill plots for further evaluation. This is when brewers are shown the hops and field yield is studied
- Years 9-10: Extensive brewing trials and agronomic studies. Often sponsored on 1 acre fields

AMERICAN HOP VARIETIES 2013-2017

Top 10 Pacific Northwest Hop Varieties (acreage)

Rank	2013	2014	2015	2016	2017
1	Cascade	Cascade	Cascade	Cascade	Cascade
2	Zeus	Zeus	Centennial	Centennial	Centennial
3	Summit	Centennial	Zeus	Citra®, HBC 394	Citra®, HBC 394
4	Columbus/Tomahawk	Summit	Simcoe®, YCR 14	Simcoe®, YCR 14	Simcoe®, YCR 14
5	Centennial	Simcoe®, YCR 14	Citra®, HBC 394	Zeus	Zeus
6	Nugget	Citra®, HBC 394	Mosaic®, HBC 369	Mosaic®, HBC 369	Mosaic®, HBC 369
7	Chinook	Columbus/Tomahawk	Chinook	Chinook	Chinook
8	Citra®, HBC 394	Chinook	Columbus/Tomahawk	Summit	Willamette
9	Simcoe®, YCR 14	Nugget	Summit	Willamette	Summit
10	Super Galena™	Willamette	Willamette	Columbus/Tomahawk	Columbus/Tomahawk

Source: Hop Growers of America

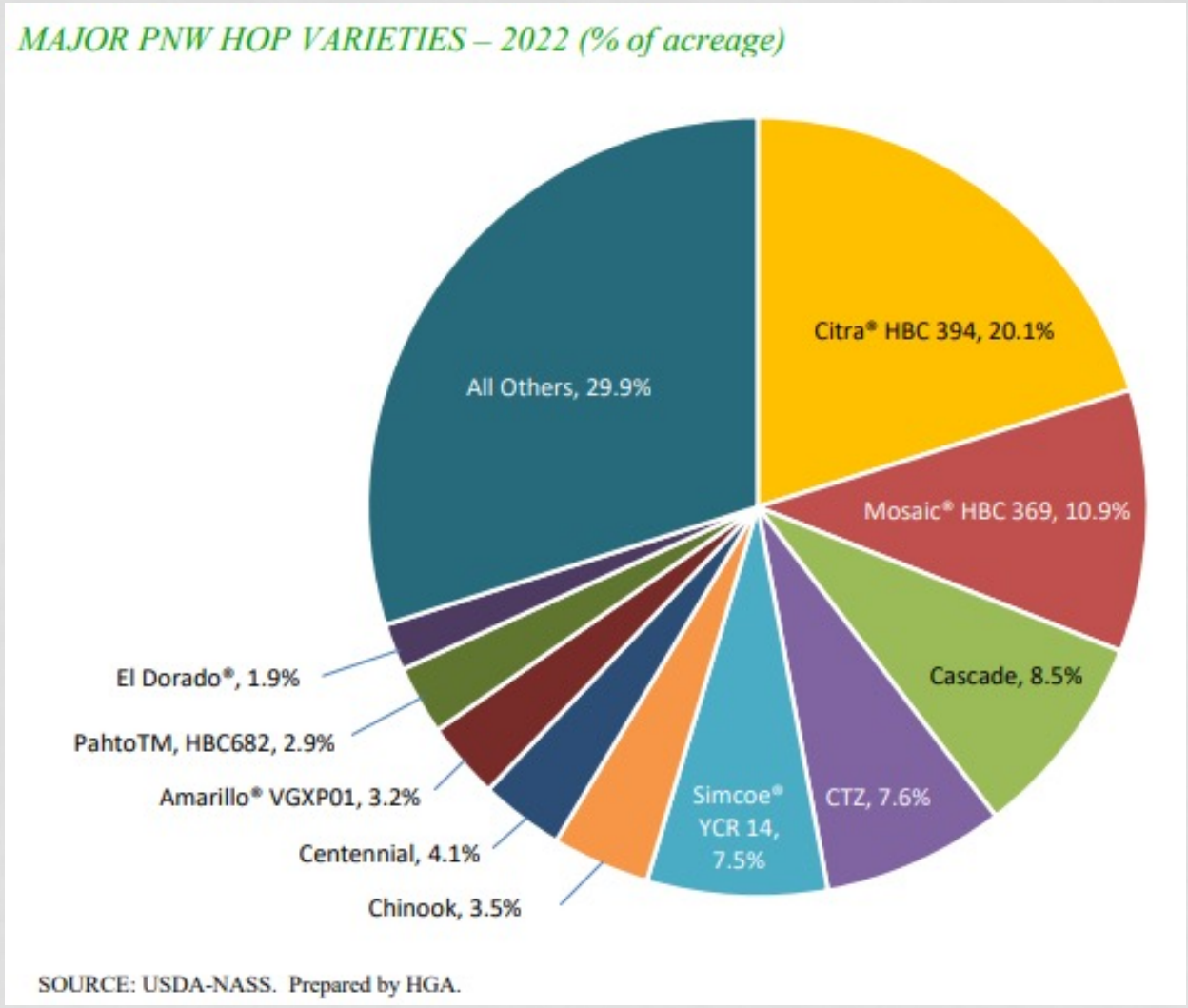
AMERICAN HOP VARIETIES 2017-2022

Top 10 Pacific Northwest Hop Varieties (acreage)

Rank	2017	2018	2019	2020	2021	2022
1	Cascade	Citra®, HBC 394	Citra®, HBC 394	Citra®, HBC 394	Citra®, HBC 394	Citra®, HBC 394
2	Centennial	CTZ	CTZ	CTZ	Mosaic®, HBC 369	Mosaic®, HBC 369
3	Citra®, HBC 394	Cascade	Cascade	Mosaic®, HBC 369	CTZ	Cascade
4	CTZ	Centennial	Simcoe®, YCR 14	Simcoe®, YCR 14	Cascade	CTZ
5	Simcoe®, YCR 14	Simcoe®, YCR 14	Mosaic®, HBC 369	Cascade	Simcoe®, YCR 14	Simcoe®, YCR 14
6	Mosaic®, HBC 369	Chinook	Centennial	Centennial	Centennial	Centennial
7	Chinook	Mosaic®, HBC 369	Amarillo®	Pahto®, HBC682	Pahto®, HBC682	Chinook
8	Willamette	Amarillo®	Chinook	Amarillo®	Amarillo®	Amarillo®
9	Summit	Pahto®, HBC682	Pahto®, HBC682	Chinook	Chinook	Pahto®, HBC682
10	Apollo™	Summit	Summit	El Dorado®	El Dorado®	El Dorado®

Source: Hop Growers of America

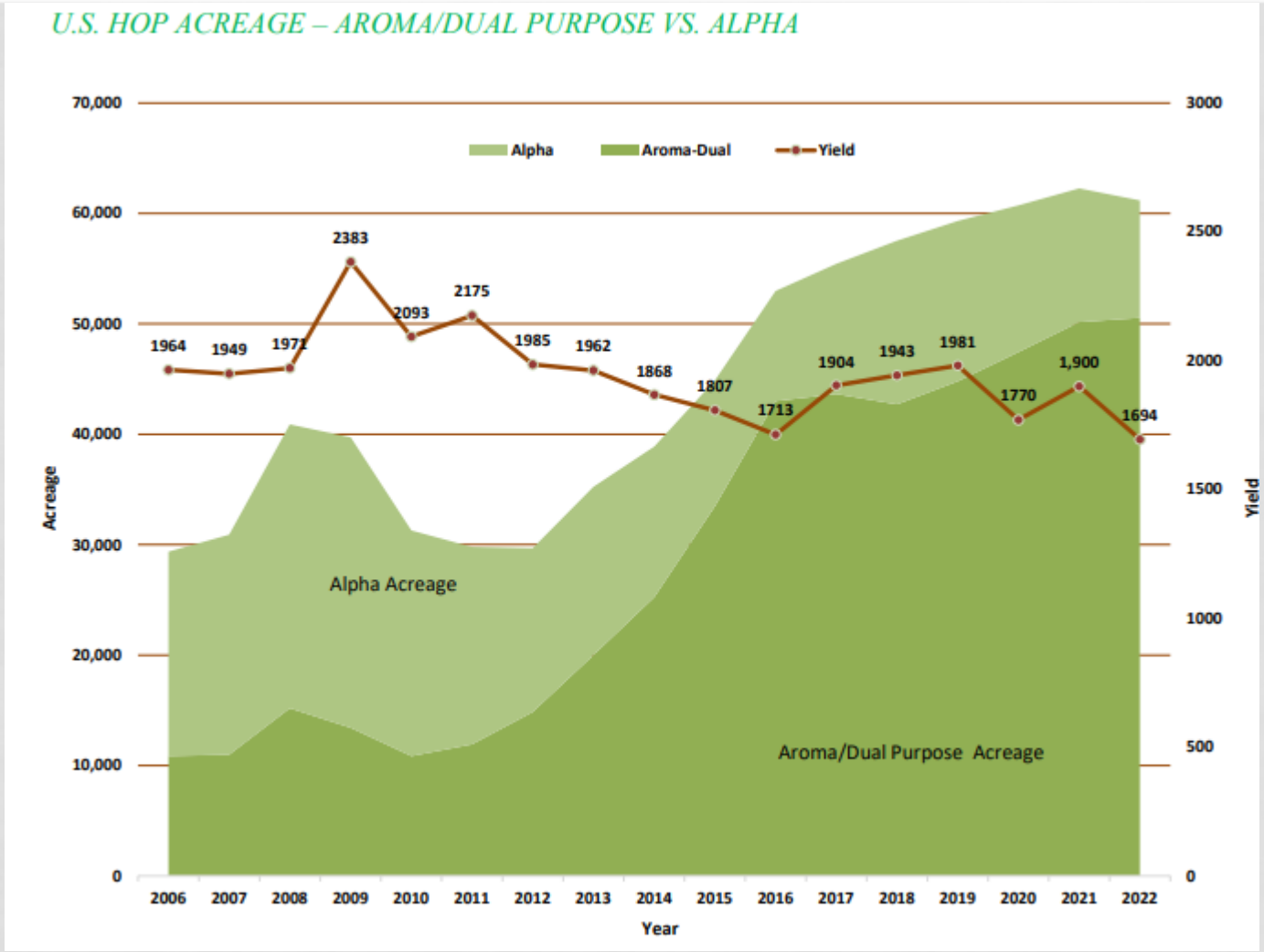
AMERICAN HOPS % OF ACREAGE



HOP CLASSIFICATIONS

- Alpha hops
  - Hops used primarily for bittering potential
  - Examples include Warrior, Magnum, Polaris, Nugget, Bravo, Pahto
- Aroma hops
  - Hops typically used in late additions and dry hopping for aromatics
  - Examples include landrace/noble varieties (Mittelfruh, Spalter, Goldings) Cascade,
- Dual purpose hops:
  - Highly aromatic hops with high alpha acid content/bittering potential
  - Examples include Centennial, Amarillo, Citra, Mosaic

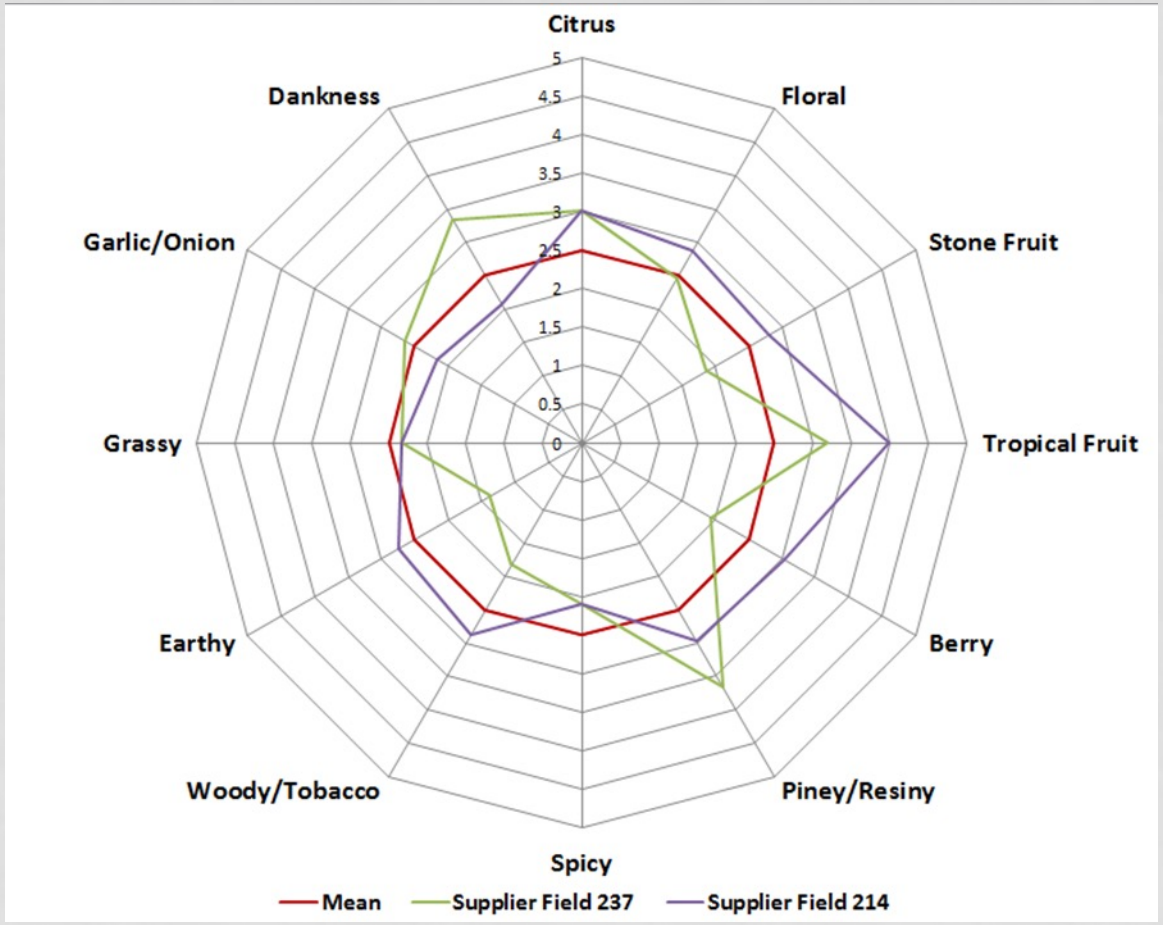
ALPHA VS AROMA



THOUGHTS ON HOP FLAVOR IMPACTS

- Variety
- Product Type (T90 pellet, T45 pellet, whole hops, extracts)
  - Pelletizing process
- Differences within the variety:
  - Terroir
  - Bine Age/varietal evolution through multiple generations
- Harvest year and climate in growing and harvest season
- Hop age: Older hops develop aldehydes and fatty acids which contribute to off flavors
- Growing and harvesting process and quality: Harvest time, picking, kilning, aging
- Brewing processes: hot side and cold side

TERROIR



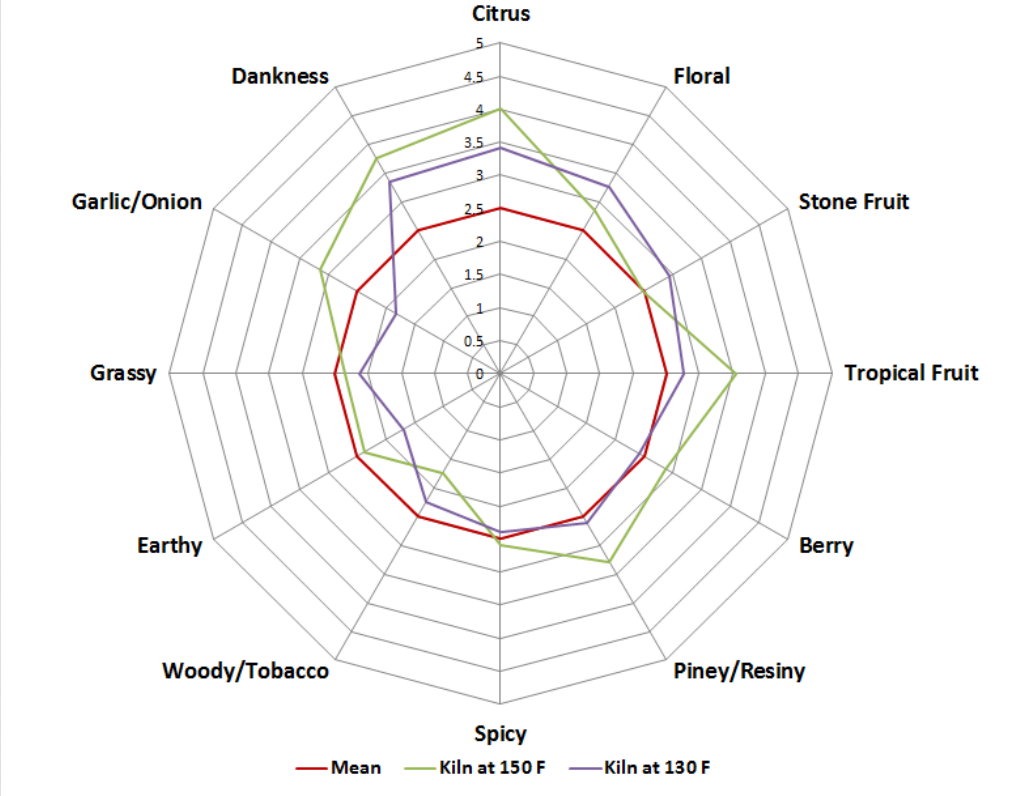
Oregon Cascades:
Received Brewers Cuts from 2 separate lots of Cascades from the same supplier and the same ranch.

Rubbing showed pine on 237 and a more classic floral/fruit on 214. Dry hop tasting results confirmed these observations.

Per Supplier:
Location 214 was east side of Willamette River, on a hillside, 9.2% Alpha Acid.

Location 237 was west side of the Willamette on low alluvial plain, 8.1% Alpha Acid.

KILN TEMPERATURE



- Cascades were kilned at 2 different temperatures and brewer's cuts were evaluated using Dry Hop Trial method.
- Kilning at 150° F showed more citrus, pine, garlic/onion, and dankness, while kilning at 130° F showed more floral.
- Preference: 4 preferred higher temperature kilning, 4 preferred lower temperature kilning, 2 had no preference.
- More "true to type": 6 tasters felt that the lower kilning temperature was more classic Cascade and 4 abstained from voting.

EVALUATING HOPS

- Traditional way is to do hop rubs, whole hops, brewers cuts from a bale.
  - Hop samples rubbed vigorously between hands, then smell odor on hands
  - Visual inspection for environmental damage, pests, etc
- Pellets can be evaluated:
  - "Hop" grinder
  - Hop Teas ASBC method: mix pellets in ambient/cool water and mix. Use a French Press coffee maker to separate, and then evaluate aroma:
    - 20 g hop pellets
    - 1 liter water, 77°F/25°C
    - French Press
    - Stir plate 20 minutes
  - Small scale beer trials-dry hop trials at a rate of 1lb/bbl (.516 oz/gallon, 14.6 gm/gallon)

HOP CHEMISTRY

- Most components wanted by brewers are in the lupulin glands
- Alpha Acids: Humulones provide bitterness, foam and flavor stability when isomerized in the kettle boil (temperature above 185°F)
  - Cohumulone, humulone and adhumulone
  - Cohumulone once perceived as being a coarser bitterness
- B acids: Lupulones and hulupones. Also contribute a bit to bitterness, as a beer ages
- Essential Oils:
  - Hydrocarbons: Most volatile
  - Oxygenated hydrocarbons
  - Sulfur compounds/thiols-incredibly aromatic at very low concentrations. Grapefruit and tropical, but can also contribute onion and garlic

MORE ON THIOLS

- 4MMP: Black Currant and passionfruit
  - High levels: Citra, Simcoe, Nelson Sauvin, Galaxy, Mosaic, Apollo.
  - Also, at slightly lower levels: Chinook, Cascade Centennial, Amarillo, Hallertau Blanc, Mandarina Bavaria
- 3MH: Grapefruit, rhubarb, exotic fruit:
  - 99% of 3MH is bound in hops and must be freed
  - Can be converted to 3MA (passionfruit, guava) during fermentation
  - Best to use these hops in late hopping (whirlpool)
  - High levels: Cascade, Hallertau, Citra, Calypso
- 3MO: Preaches and stone fruit
- 3M4MP: Rhubarb and citrus
- Brewing Tips:
  - Add hops with high concentrations of bound thiols in late hopping (EOB and whirlpool)
  - Add hops with high concentrations of free thiols in dry hop
  - 4MMP, 3MH, and 3MA and other thiols don't survive in packaged beer aging after a few months

BREWING WITH HOPS

- Brewhouse Additions (Hot Side)
  - Mash and 1st wort hopping
  - Kettle hopping
  - Whirlpool hopping
- Utilization:
  - Formulas and impacts
- Fermentation
  - Bitterness changes
  - Dry hopping
  - Post fermentation dry hopping
- Considerations on water chemistry
- Considerations on formulation and hop blending
- Hop products

MASH HOPPING AND 1ST WORT HOPPING

- Mash hopping
  - Works well when using thiolizing yeast strains
  - Potentially helps with decreasing oxidation: Alpha acids combine with Iron and Copper
  - Other benefits?
- 1st Wort Hopping
  - Was used frequently by German and British brewers in the early 20th century to try and increase hop utilization
  - German brewers claimed a finer aroma
  - Will contribute to more bitterness than traditional boil additions: 5-10% more utilization
  - Theory that oxidation during kettle filling allows for oxidation of oils, making them more soluble and increasing aromatics
  - Theory that aroma compounds will bind with malt compounds and make them less volatile during the boil, increasing aromatics?

KETTLE HOPPING

- Traditional:
  - Bitter (early)/ Flavor (mid-late boil)/Aroma (end of boil) additions
  - All of these addition contribute, primarily, bitterness!
- Variations being used now designed to reduce bitterness and/or increase oil extraction:
    - Hazy IPAs
    - Hop Bursting: Little to no bittering hops, almost all bitterness comes from whirlpool
    - Lower temperature whirlpool hopping
- Hop selections:
  - Finer bitterness with low alpha hops early in the boil. Good for pilsners. Avoid using too much
  - Risk of unpleasant bitterness with some high alpha varieties. Bittering hop varieties aren't 100% interchangeable

IMPACTS ON HOP UTILIZATION

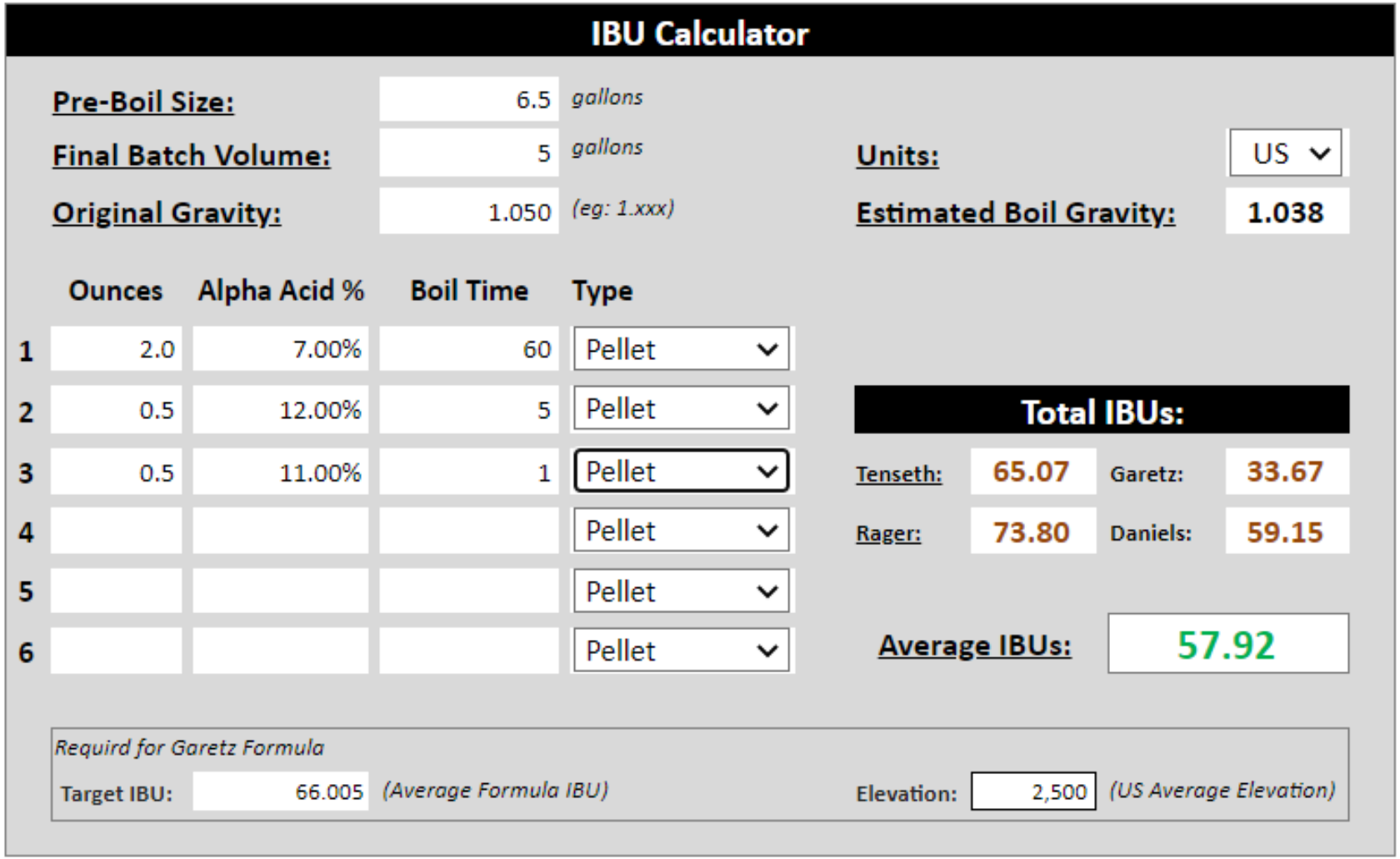
- Hop form/ hop product used
- Boil time: Not a linear increase, more than 90 minutes start seeing changes to iso-alpha acids
- Boil vigor-increases utilization
- Kettle geometry
- Wort gravity: utilization decreases as gravity increases, however maximum IBU potential occurs with higher gravity beers
- Wort boil temperature: higher altitude lowers utilization
- Wort pH: Higher pH increases utilization, but high pH negatively impacts trub formation, protein and yeast nutrition
- Cohumulone more efficient at isomerizing than other humulones

- Utilization formula:
- Utilization = $\frac{\text{iso alpha acids in wort x 100}}{\text{alpha acids added to wort}}$
- IBU = $\frac{\text{Quantity hops x alpha acid content x utilization x .749}}{\text{Volume}}$

IBU CALCULATIONS

- Several methods available top homebrewers and brewers
- All have inconsistencies, but most provide a good estimate
- Calculations do not usually take into account impact of fermentation:
  - pH drop during fermentation reduces solubility of iso-alpha acids
  - This can result in 25-35% drop in bitterness from wort to finished beer
- Calculated bitterness vs perceived bitterness vs analytical bitterness

IBU CALCULATION: SOURCE: HTTPS://HOMEBREWACADEMY.COM/IBU-CALCULATOR/



IBU Calculator

Pre-Boil Size:	6.5	*gallons*	
Final Batch Volume:	5	*gallons*	**Units:** US
Original Gravity:	1.050	*(eg: 1.xxx)*	**Estimated Boil Gravity:** 1.038

	Ounces	Alpha Acid %	Boil Time	Type
1	2.0	7.00%	60	Pellet
2	0.5	12.00%	5	Pellet
3	0.5	11.00%	1	Pellet
4				Pellet
5				Pellet
6				Pellet

Total IBUs:

Tenseth:	65.07	**Garetz:**	33.67
Rager:	73.80	**Daniels:**	59.15

Average IBUs: 57.92

Requird for Garetz Formula

Target IBU: 66.005 *(Average Formula IBU)*

Elevation: 2,500 *(US Average Elevation)*

THOUGHTS ON BITTERNESS

- Tasters can't distinguish different levels of IBUs past 60 IBUs
- Significant personal differences in solubility of bittering compounds in saliva. Affects bitterness perception
- Quality of bitterness: soft, sharp, lingering, drying, resiny
- Sweetness matters
- Alcohol strength matters, both to IBU analysis and perceived bitterness
- Water chemistry matters
- Hazy IPAs softer bitterness due to lower additions and water chemistry. Occasionally higher perceived bitterness/hop burn due to excessive dry hop regimen, especially fast aged, uncentrifuged or unfiltered beers

WHIRLPOOL HOPPING

- Utilization can be higher than 20%, so be careful with time
- Use hops high in bound thiols to allow time for flavors to develop through action of B-Lyase
  - Saaz, Citra, Calypso
- If brewing a hoppy beer, consider using hops where volatiles survive longer (next slide)
  - Centennial, Citra, Talus, Equanot, are good
  - Limit use of hops like Cascade, Cashmere, Azacca
- Use a blend if doing heavy whirlpool hopping
- Hop Bursting
- Whirlpool hopping lighter styles (Pilsners) is very popular
- Cold whirlpool hopping reduces isomerization and bitterness and retains volatiles.

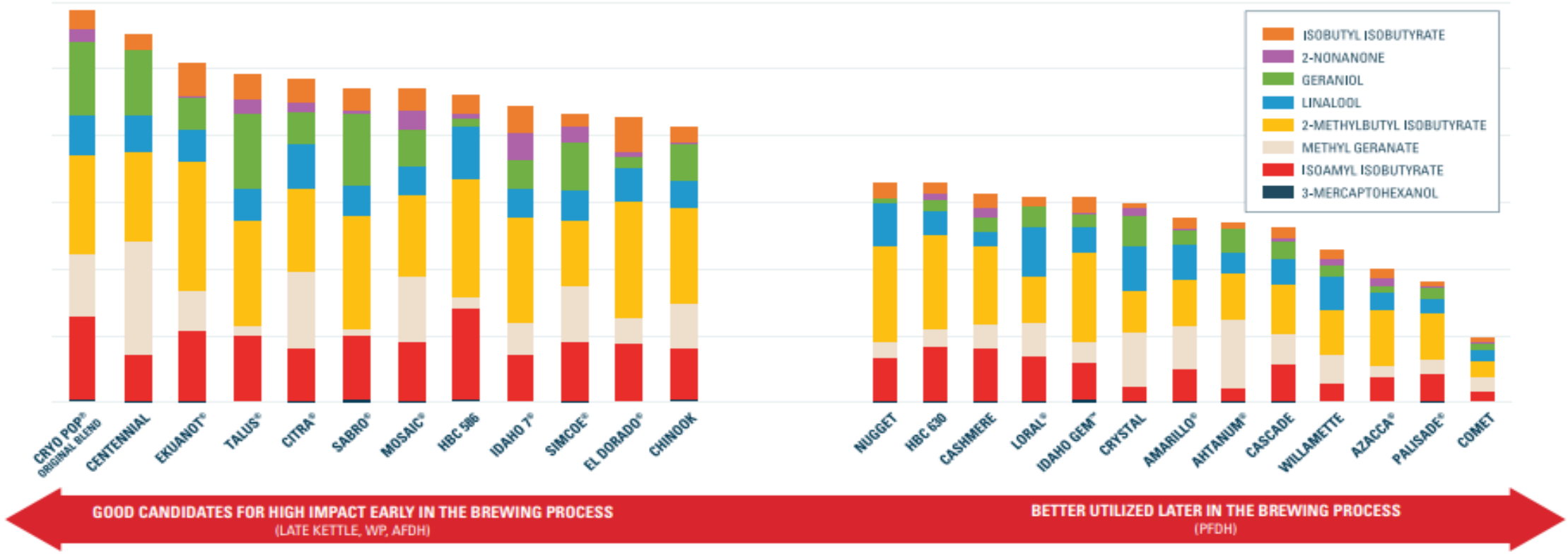
YCH SURVIVABLES RESEARCH

THE SURVIVABLES GRAPH

GC-QTOF and GC-SCD technology is useful for research purposes, as well as in the development of practical tools which help brewers make more informed decisions about when and how to use hops.

ANSWERS SUCH QUESTIONS AS:

- What variety should I use?
- Where in the process should I use it?
- Which hops work together in combination?
- How can I use a variety to its maximum effect?



YCH SURVIVABLES RESEARCH

1. USE HIGH SURVIVABLES HOPS EARLY (OR LATE)

Hops with higher concentrations of survivable compounds have a better likelihood of being successful when used earlier in the brewing process than hops with low concentrations of these same compounds. Early additions include late kettle, whirlpool, and active fermentation dry hopping (AFDH).

EXAMPLE

Ekuanot® is likely a better choice for high-impact whirlpool hopping than Palisade®.

This is because Ekuanot® contains higher concentrations of beer soluble compounds that can survive heat and fermentation activity.

2. USE LOW SURVIVABLES HOPS LATE

Similarly, we can say that hops with lower concentrations are likely to find better success and a more positive impact in beer when used later in the process, such as post fermentation dry hopping (PFDH).

EXAMPLE

Willamette will likely make a higher impact in finished beer if used later in the brewing process.

This is because Willamette contains smaller concentrations of beer soluble compounds that can survive heat and fermentation activity.

THIOLIZING YEAST PRODUCTION

- Yeast strains that free up bound thiols during fermentation to produce massive tropical fruit
- Most thiol precursors are found in malt, though hops have some as well
  - Lighter kilned malts have more than roasted malts
- Mash hopping is effective for enhancing thiol release from hops. Certain hops do better-those with high levels of 3MH precursors: Cascade, Saaz, Motueka, Calypso, Hallertau

BIOTRANSFORMATION

- Yeast and hop combinations can produce very complex results
- Two primary biotransformation pathways:
  - Yeast with B-glucosidase activity or exo-B-glucanase can cleave the bonds of glycosides and release terpene alcohols, or use commercially available B Glucosidase. Mostly wild yeast and wine yeast, non-sachharomyces strains
  - Biotransformation of terpenoid alcohols-requires hops and yeast compounds:
    - Geraniol→ Citronellol, Linalool→Terpineol
    - Most biotransformation happens during yeast growth phase
- High geraniol hops: Citra, Centennial, Mosaic, Amarillo, Chinook, Crystal (El Dorado, Idaho 7?)
- High linalool hops: Crystal, Mt Hood, Fuggle, Tettnang, Citra, Nugget
- Combine B Glucosidase with high geraniol hops?
- Wine yeasts, wild yeasts, London Ale III, Kviek yeast

MID FERMENTATION DRY HOP

- Sugar can suppress biotransformation activity
- Higher pH enhances it
- Debate and different practices about adding hops day 0, day 1, or day 4-5
- Biotransformation and free thiol release happens quickly
- Geraniol >>Citranellol is the biotransformation that creates “juicy”
- Thiol release is what creates tropical/passionfruit

POST FERMENTATION DRY HOP

- To remove the yeast or not?
- Temperature
- Humulinones and polyphenols from dry hop addition can add bitterness
- Optimum contact time:
  - 24 hours?
  - 2-3 days? 1 week plus?
- Addition rates and diminishing returns
  - 3lbs/bbl max?
  - Hop Haze at higher levels, and hop burn
- Hop flavor stability impacted by:
  - Beer oxidation
  - Filtration
  - Time
  - Packaging material/scalping

HOP CREEP

- Re-start of fermentation after dry hopping
  - Hops have malt enzymes (amylase, amyloglucosidase, etc.) that break down unfermentable sugars to fermentable ones, which results in more yeast fermentation activity after dry hopping
  - Can result in increased diacetyl in aging tank
  - Can result in refermentation in package and excess CO2
- Contributors:
  - Hop Variety: All hops. Amarillo and Cascade noted as being significant
  - Timing and temperature of dry hop, and contact time in beer
  - Lower kiln temperatures= more active enzymes in hops. Lower kilning temperatures were popularized several years ago to preserve oils and reduce onion/garlic
  - Oxygen pick up during dry hopping
- Was this a key element of IPA in the 1800s? First studied in early 1900s

THE IMPORTANCE OF WATER CHEMISTRY

- Salts addition impacts pH:
  - Optimal mash pH 5.2-5.4. Best hop isomerization/utilization with higher pH
- Calcium and sulfate accentuate hop bitterness and hop brightness
- Chloride softens hop presence and intensity, can enhance maltiness
- Chloride to Sulfate ratio
  - Important distinction for IPA vs Hazy/Juicy IPA styles
  - 1:1 ratio is considered balanced, but high levels of both is unpleasant and minerally
  - Concentration does not track with ratio, meaning that a ratio at low concentrations has a completely different effect than at high concentrations
  - Target 1:5 ratio for West Coast IPA
  - Target 2:1 or 3:1 for Hazy

WATER CHEMISTRY IN BEER

- West Coast IPA: Calcium and sulfate enhance crispness and hop bitterness
  - 100-150 ppm Calcium
  - 200+ ppm Sulfate (up to 400)
  - 50-70 ppm Chloride
- Hazy IPA: High chloride and low sulfate softens hop bitterness
  - 75-120 ppm Calcium
  - 50-75 ppm Sulfate
  - 150-200 ppm Chloride
- Lagers and Pilsners: low mineral content to preserve the elegant bitterness from noble hops

MIXING HOPS

- Some hop varieties are known to “play well” with others:
  - Strata
  - Pacific Sunrise
  - Idaho 7
  - Chinook
  - Cascade
  - Amarillo
- Single hop beers vs hop salads
  - Single hop beers are fun and interesting, but can be one-dimensional or overwhelming
  - Hop salads used by professional brewers for mitigating flavor changes in different crop years

CHOOSING HOPS

- When blending, pick complementary, but different flavors
  - Azacca (pineapple) pairs nicely with Citra (citrus and peach)
  - Simcoe (resiny and peach) pairs great with Centennial (lemony and piney)
  - Chinook and Cascade always work well together
  - Idaho Gem (jolly Rancher) and Idaho 7
  - German hops: Saphir pairs well with noble varieties, and adds hints of fruitiness
- Be wary of strong flavored varieties. Some examples:
  - Mosaic overwhelms just about everything, so dial it back
  - El Dorado can dominate many other hop varieties
  - Amarillo-intense over-ripe tropical fruit
  - Sabro and Talus can be dominatingly herbal
  - Summit, Polaris tend to be overwhelmingly garlic

HOP PRODUCTS

- Whole Hops: most traditional, bulky, poor storage once opened
  - Preferred by traditional brewers
- T90 Pellets: Most common, preserves most of the hop cone (90%)
  - Technology advances have made T90 pellets very close to whole hops
- T45 pellets-concentrated lupulin-very similar to Cryo/Lupomax,/CGX products
  - Flavor differences from T90
- Cryo/Lupomax/CGX/Lupulin pellets/powders: Concentrated and processed cryogenic/cold
  - Pellets preferred by brewers vs powders
  - Usage ~50% required vs T90 pellets (YMMV)
  - Processed under extreme cold
  - Flavor impacts
- Fresh hops (unkilned, undried)
  - Use at 5:1 ratio vs pellets as a starting point
  - Watch for veggy flavors

HOP PRODUCTS

- C02 extracts
  - Generally used for bittering. 50+% alpha acids concentrated
  - Better storage (volume and stability)
- Hop Oils
  - Do not provide same flavor as pelletized hops
  - Best used to augment traditional dry hopping
  - Adds shelf life
- Special extract products:
  - Tetra, Rho, Hexa: Altered hop products used by larger brewers to enhance bitterness, foam, reduce lightstruck, etc
  - JW Haas Flex, Incognito, Spectrum, Steiner Hopflow, Salvo: Liquid hop products for use at various brewing steps, increases efficiencies
  - Steiner product