

# Harmful and Potentially Harmful Constituents Analysis of North American ENDS \*

by

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## SUMMARY

The objective of this study was to create a North American e-cigarette, or electronic nicotine delivery system (ENDS), market map representative of the 2020 and 2021 commercial market for analysis of harmful and potentially harmful constituents (HPHCs) and other chemicals in aerosol. The study consisted of 14 brands (seven closed pod-based, four open (refillable) pod-based, two cigalike, one disposable) and analyzed multiple e-liquid formulations per brand with varying labelled nicotine concentrations and flavors, equating to 35 unique tested ENDS. Aerosol was generated using two puffing regimes (ISO 27068 and intense) and analyzed for primary constituents, metals, carbonyls, and glycidol in a head-to-head comparison in the same testing laboratory. Nicotine yields per puff ranged from 0.045 mg/puff for the lowest yielding ENDS under the ISO 27068 puffing regime to 1.11 mg/puff for the highest yielding ENDS under intense puffing conditions. For carbonyls, all ENDS generated quantifiable amounts of acetaldehyde, acrolein, and formaldehyde in collected aerosol, irrespective of puffing regime, with an increase in yields observed under intense puffing compared to ISO 27068 puffing for the majority of tested ENDS. For metals, the ENDS aerosol yielded nickel (Ni) ranging from below limits of detection (BLOD) to >30 ng/puff, while quantifiable levels of chromium (Cr), copper (Cu), and lead (Pb) were only associated with select ENDS. All tested ENDS aerosol contained quantifiable glycidol ranging

from 0.003 to >1.00 µg/puff for ISO 20768 and 0.005 to 1.10 µg/puff for intense puffing regimes. As a category, ENDS aerosol showed significantly reduced levels of HPHCs compared to 1R6F combustible cigarette (CC) smoke on a per nicotine basis. However, there was variability among ENDS and the aerosol of some ENDS products produced increased levels of specific HPHCs (e.g., formaldehyde and nickel) compared to 1R6F CC smoke. The observed HPHC variations appear to be primarily dependent on device design. In summary, this work is one of the most comprehensive analyses of HPHCs for North American ENDS using validated analytical methods in the same test facility for a head-to-head comparison. [Contrib. Tob. Nicotine Res. 33 (2024) 189–216]

## KEYWORDS

Electronic Nicotine Delivery Systems (ENDS); e-cigarette; market map; HPHCs; nicotine.

## ZUSAMMENFASSUNG

Ziel dieser Studie war es, eine nordamerikanische Markt-karte für E-Zigaretten oder elektronische Nikotinabgabe-systeme (ENDS) zu erstellen, die repräsentativ für den kommerziellen Markt in den Jahren 2020 und 2021 ist, um schädliche und potenziell schädliche Inhaltsstoffe (HPHC)

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und andere Chemikalien in Aerosolen zu analysieren. Die Studie umfasste 14 Marken (sieben geschlossene Pods, vier offene (nachfüllbare) Pods, zwei zigarrenähnliche Produkte und ein Einwegprodukt) und analysierte mehrere E-Liquid-Formulierungen pro Marke mit unterschiedlichen Nikotinkonzentrationen und Geschmacksrichtungen, was 35 getesteten ENDS entspricht. Das Aerosol wurde mit zwei Zugverfahren (ISO 27068 und intensiv) erzeugt und in einem direkten Vergleich im selben Testlabor auf primäre Bestandteile, Metalle, Karbonylverbindungen und Glycidol untersucht. Die Nikotinausbeute pro Zug reichte von 0,045 mg/Zug für das ENDS mit der geringsten Ausbeute nach ISO 27068 bis zu 1,11 mg/Zug für das ENDS mit der höchsten Ausbeute unter intensiven Zugbedingungen. Bei den Carbonylen erzeugten alle ENDS messbare Mengen an Acetaldehyd, Acrolein und Formaldehyd im gesammelten Aerosol, unabhängig von der Art der Züge, wobei bei intensiven Zügen im Vergleich zum Ziehen nach ISO 27068 bei der Mehrheit der getesteten ENDS höhere Werte beobachtet wurde. Was die Metalle betrifft, so enthielt das ENDS-Aerosol Nickel (Ni) im Bereich von unter der Nachweisgrenze (BLOD) bis  $>30$  ng/Zug, während quantifizierbare Werte von Chrom (Cr), Kupfer (Cu) und Blei (Pb) nur mit ausgewählten ENDS in Verbindung gebracht wurden. Alle getesteten ENDS-Aerosole enthielten quantifizierbares Glycidol in einer Bandbreite von 0,003 bis  $>1,00$   $\mu\text{g}/\text{Zug}$  bei ISO 27068 und 0,005 bis 1,10  $\mu\text{g}/\text{Zug}$  bei intensivem Inhalieren. Als Kategorie wiesen ENDS-Aerosole im Vergleich zu 1R6F-Zigarettenrauch (CC) signifikant niedrigere HPHC-Werte bezogen auf Nikotin auf. Allerdings gab es Unterschiede zwischen den einzelnen ENDS-Produkten, und das Aerosol einiger ENDS-Produkte wies im Vergleich zu 1R6F-CC-Rauch erhöhte Werte bestimmter besonders besorgniserregender Stoffe auf (z. B. Formaldehyd und Nickel). Die beobachteten HPHC-Schwankungen scheinen in erster Linie vom Gerätedesign abhängig zu sein. Zusammenfassend lässt sich sagen, dass es sich bei dieser Arbeit um eine der umfassendsten HPHC-Analysen für nordamerikanische ENDS handelt, bei der validierte Analysemethoden in derselben Prüfeinrichtung für einen direkten Vergleich verwendet wurden. [Contrib. Tob. Nicotine Res. 33 (2024) 189–216]

## RESUME

L'objectif de cette étude était de créer une carte du marché nord-américain de l'e-cigarette, ou système électronique d'administration de nicotine (ENDS), représentative du marché commercial de 2020 et 2021 pour l'analyse des constituants nocifs et potentiellement nocifs (HPHC) et d'autres produits chimiques en aérosol. L'étude a porté sur 14 marques (sept à dosettes fermées, quatre à dosettes ouvertes (rechargeables), deux à cigares, une jetable) et a analysé plusieurs formulations d'e-liquide par marque, avec différentes concentrations de nicotine et différents arômes, ce qui correspond à 35 ENDS uniques testés. L'aérosol a été généré en utilisant deux régimes de bouffée (ISO 27068 et intense) et analysé pour les constituants primaires, les métaux, les carbonyles et le glycidol dans une comparaison tête à tête dans le même laboratoire

d'essai. Les rendements en nicotine par bouffée allaient de 0,045 mg/bouffée pour les ENDS ayant le rendement le plus faible selon le régime de bouffée ISO 27068 à 1,11 mg/bouffée pour les ENDS ayant le rendement le plus élevé dans des conditions de bouffée intense. En ce qui concerne les carbonyles, tous les ENDS ont généré des quantités quantifiables d'acétaldéhyde, d'acroléine et de formaldéhyde dans l'aérosol collecté, quel que soit le régime d'inhalation, avec une augmentation des rendements observés lors d'une inhalation intense par rapport à l'inhalation ISO 27068 pour la majorité des ENDS testés. En ce qui concerne les métaux, l'aérosol des ENDS contenait du nickel (Ni) dans une fourchette allant de moins de la limite de détection (BLOD) à  $>30$  ng/puff, tandis que des niveaux quantifiables de chrome (Cr), de cuivre (Cu) et de plomb (Pb) n'ont été associés qu'à certains ENDS. Tous les aérosols ENDS testés contenaient du glycidol quantifiable allant de 0,003 à  $>1,00$   $\mu\text{g}/\text{bouffée}$  pour la norme ISO 27068 et de 0,005 à 1,10  $\mu\text{g}/\text{bouffée}$  pour les régimes de bouffées intenses. En tant que catégorie, les aérosols d'ENDS ont montré des niveaux significativement réduits de HPHC par rapport à la fumée de cigarette combustible (CC) 1R6F sur la base de la nicotine. Cependant, il y avait une variabilité entre les ENDS et l'aérosol de certains produits ENDS produisant des niveaux accrus de HPHC spécifiques (par exemple, le formaldéhyde et le nickel) par rapport à la fumée de CC 1R6F. Les variations de HPHC observées semblent dépendre principalement de la conception du dispositif. En résumé, ce travail est l'une des analyses les plus complètes des HPHC pour les ENDS nord-américains, utilisant des méthodes analytiques validées dans la même installation d'essai pour une comparaison directe. [Contrib. Tob. Nicotine Res. 33 (2024) 189–216]

## 1. INTRODUCTION

A large body of research is available describing the smoke constituents, including HPHCs, of combustible cigarettes (CCs). These studies are often grouped by geographical region since cigarette design and construction can vary depending on consumer preferences in a regional market. Several publications include “market map” style comparisons illustrative of the expected yield of certain smoke constituents in CCs of interest contrasted with an estimate of the respective CC market “mean” smoke constituent yield (1–13). There are many benefits of CC market map studies. Most notably, they aid regulators and manufacturers in the comparison of smoke constituent exposure between products based on statistical criterion that considers assay, inter-laboratory, and temporal variability (14). While the development of CC market maps has benefited greatly from decades of available literature on smoke constituent yield, limited design variability, and the ready availability of reference CC products with well characterized yields (15–17), similar attempts at the creation of a market map of electronic nicotine delivery systems (ENDS) aerosol select constituent yields have been hindered by several complicating factors, including rapid advancement in ENDS design, lack of standardized ENDS-specific analytical methods, and the absence of relevant ENDS

reference products (18–21). To date, few published market map style studies have been conducted on ENDS that include multiple classes of HPHCs (e.g., carbonyls, metals, volatiles, etc.) in the same study. Most notably, BELUSHKIN *et al.* (22) investigated 34 commercial ENDS and 57 e-liquids, including closed (non-refillable) and open (refillable) systems, for products purchased (via point of sale and internet) between 2015 and 2018 available in U.K., Poland, France, South Africa, and Canada. Chemical characterization of aerosol generated using standardized puffing conditions was focused on carbonyls, however, additional data was provided on tobacco-specific nitrosamines (TSNAs), benzo[*a*]pyrene (BaP), volatiles, and metals. In general, the authors found that carbonyls were quantifiable and highly variable in almost all of the tested products while TSNAs, BaP, volatiles, and metals were typically below method limits of detection. A number of studies using ENDS have been conducted on particular classes of HPHCs in aerosol, most commonly carbonyls (23–28) or metals (29–34). These earlier works help guide and aid future studies that can narrow the focus of aerosol constituents that are measurable while leveraging the advances in standardized laboratory procedures supported by the International Organization of Standardization (ISO) and Cooperation Centre for Scientific Research Relative to Tobacco (CORESTA).

Recently, regulatory agencies around the world, including United States Food and Drug Administration (U.S. FDA), European Union (EU) and United Kingdom Medicines and Healthcare products Regulatory Agency (UK MHRA), have addressed some ambiguity regarding minimum aerosol analyte data required for marketing and sale of ENDS, greatly incentivizing the development of ENDS-specific analytical methods. ENDS manufacturers can now provide focused analyte lists with accurate aerosol yields, but comparison to CC is complicated since the products are different, especially the ENDS consumable size and nicotine concentration, not to mention that on a per puff basis for ENDS a higher aerosol mass per puff is inversely related to the number of puffs per consumable. To tackle the challenge, ENDS product aerosol constituent yields are now routinely benchmarked against reference cigarettes (such as the University of Kentucky Reference Cigarettes 3R4F or 1R6F), usually on a per-mg nicotine basis (21, 22, 35–39). For example, CUNNINGHAM *et al.* (21) investigated two commercial ENDS and five e-liquids, evaluating their aerosol constituent yields against each other and 1R6F, and found that 16 of the 19 HPHCs and other chemical compounds were not detected in the ENDS, and that levels of the nine WHO Tobacco Product Regulation (TobReg) priority cigarette smoke toxicants were more than 99% lower in the aerosols of the tested ENDS as compared with 1R6F on a per-mg of nicotine basis. CHEN *et al.* (35) investigated the JUUL System with Virginia Tobacco and Menthol flavored pods at two nicotine concentrations with two different puffing regimes and found that all four JUUL system aerosols tested had constituent reductions greater than 98% compared to 3R4F mainstream smoke levels when normalized to mg of nicotine. MARGHAM *et al.* (36) investigated one commercial ENDS product using three e-liquids and found that select aerosol constituent yields in e-cigarette aerosols were significantly lower than those in

3R4F cigarette smoke (on per-mg of nicotine basis), with 68.5% to >99% reductions and 88.4% to >99% reductions using the non-intense and intense smoke regimes (ISO 3308 and 20778), respectively. These publications support the overall conclusion of researchers that aerosol constituent yields, including those of regulatory and toxicological relevance, for ENDS are significantly decreased for most compounds when compared to combustible cigarettes, i.e., commonly tested 3R4F and 1R6F.

Therefore, the objective of this study was to create a North American ENDS market map measuring relevant HPHCs (i.e., those found in previous studies to be consistently above instrument detection limits) from a wide range of closed and open system ENDS representative of the 2021 and 2022 commercial market. The study was designed to report a head-to-head comparison in the same laboratory setting utilizing ISO standards and CORESTA recommended methods (CRMs) to provide analytical ranges for select aerosol constituents representative of the ENDS category. The use of the same laboratory is a critical aspect of the study design as comparison of literature data is difficult due to inter- and intra-laboratory variability, a concept well documented in other tobacco product testing (4, 8, 14). To this end, aerosol was generated from 14 brands using at least one tobacco-type and one menthol-type e-liquid giving rise to an analytical data set comprised of primary constituents, carbonyls, metals, and glycidol for 35 unique combinations of ENDS and e-liquid formulations. Lastly, aerosol constituent yields of carbonyls, metals, and glycidol for the represented North American market ENDS were compared to constituent yield values of 1R6F CC smoke.

## 2. MATERIALS AND METHODS

### 2.1 ENDS selection criteria

ENDS were selected to represent a range of products available in the North American market (United States (US) and Canada (CAN)). Represented product design characteristics included devices intended for freebase and nicotine salt formulation e-liquids and devices of low and high coil power. For select devices, additional flavors were tested to assess whether flavors could impact HPHC yields. Products considered for analysis were favored for selection based on 2020 Nielsen data for the CAN or US ENDS market. ENDS from Mexico were not considered due to the regulatory environment at the time of the study; an Executive Order was issued by the President of Mexico in 2020 regarding the import of vaping products followed by a formal ban in 2021 (40).

### 2.2 Selected ENDS

A total of 14 brands/devices of ENDS tested in this study are summarized in Table 1. A selection of seven closed pod-based systems were chosen for aerosol constituent yield analysis: Glas (Glas Inc., Los Angeles, CA, USA), Blu MyBlu (Fontem US LLC, Charlotte, NC, USA; a subsidiary of Imperial Brands PLC, England), NJOY ACE (NJOY LLC, Scottsdale, AZ, USA), PHIX (PhixVapor, Brea, CA, USA), RELX Classic (RELX II HK LIMITED,

**Table 1. Brands/devices and e-liquid test products.**

Brands/devices	Product source	Category	E-liquid	Labelled nicotine strength (%) & form <sup>3</sup>
Glas	US	Closed pod	Signature Tobacco	5% Salt
Glas	US	Closed pod	Fresh Menthol	5% Salt
myBlu	US	Closed pod	Rich Tobacco	2.4% Freebase
myBlu	US	Closed pod	Menthol	2.4% Freebase
ACE	US	Closed pod	Classic Tobacco	5% Salt
ACE	US	Closed pod	Menthol	5% Salt
PHIX	US	Closed pod	Original Blend (Tobacco)	5% Salt
PHIX	US	Closed pod	Tobacco Menthol	5% Salt
RELX Classic	CAN	Closed pod	Classic Tobacco	5% Salt
RELX Classic	CAN	Closed pod	Mint	5% Salt
RELX Classic	CAN	Closed pod	Tangy Purple	3% Salt
RELX Classic	CAN	Closed pod	Peach Oolong	3% Salt
JUUL	CAN	Closed pod	Mint	5% Salt
JUUL	CAN	Closed pod	Golden Tobacco	5% Salt
Alto	US	Closed pod	Rich Tobacco	5% Salt
Alto	US	Closed pod	Menthol	5% Salt
Alto	US	Closed pod	Rich Tobacco	2.4% Salt
Alto	US	Closed pod	Menthol	2.4% Salt
Alto	US	Closed pod	Rich Tobacco	1.8% Salt
Alto	US	Closed pod	Menthol	1.8% Salt
Solo	US	Closed cigalike	Original (Tobacco)	4.8% Salt
Solo	US	Closed cigalike	Menthol	4.8% Salt
BIDI Stick	US	Closed disposable	Classic (Tobacco)	6% Salt
BIDI Stick	US	Closed disposable	Artic (Menthol)	6% Salt
BIDI Stick	US	Closed disposable	Gold	6% Salt
South Beach Smoke	US	Closed cigalike	Tobacco	2.4% Freebase
South Beach Smoke	US	Closed cigalike	Menthol	2.4% Freebase
iWü <sup>1</sup> (15W Max; 1.3Ω)	US	Open refillable pod	Mr. Salt-E Tobacco	4.5% Salt
iWü <sup>1</sup> (15W Max; 1.3Ω)	US	Open refillable pod	Mr. Salt-E Menthol	4.5% Salt
Nord 4 <sup>2</sup> (12W; 0.4Ω)	US	Open refillable pod	Mr. Salt-E Tobacco	4.5% Salt
Nord 4 <sup>2</sup> (12W; 0.4Ω)	US	Open refillable pod	Mr. Salt-E Menthol	4.5% Salt
Zumwalt <sup>1</sup> (13W Max; 1.2Ω)	US	Open refillable pod	Mr. Salt-E Tobacco	4.5% Salt
Zumwalt <sup>1</sup> (13W Max; 1.2Ω)	US	Open refillable pod	Mr. Salt-E Menthol	4.5% Salt
Renova ZERO <sup>2</sup> (10.5W; 1.3Ω)	US	Open refillable pod	Mr. Salt-E Tobacco	4.5% Salt
Renova ZERO <sup>2</sup> (10.5W; 1.3Ω)	US	Open refillable pod	Mr. Salt-E Menthol	4.5% Salt

<sup>1</sup> Non-adjustable power settings;

<sup>2</sup> Power output set to medium (or middle) based on manufacturer range or coil type max; Brackets = (Output Wattage Setting; Coil Resistance);

<sup>3</sup> Note: information was gathered directly from consumer-facing media, including manufacturer website, retailer website, and/or any included product literature. For most products, the accuracy of specifications published on consumer-facing media was not verifiable by other means.

Hong Kong, China), JUUL (JUUL Labs, San Francisco, CA, USA), and Vuse Alto (R.J. Reynolds Vapor Company, Winston Salem, NC, USA). In addition, two rechargeable cigalike style devices with prefilled cartridges, Vuse Solo (R.J. Reynolds Vapor Company, Winston Salem, NC, USA) and South Beach Smoke (South Beach Smoke, Louisville, KY, USA), and one disposable device, BIDI Stick (Kaival Brands Innovations Group Inc, Grant, FL, USA), were also analyzed.

The following open system devices (four refillable pod-based) were chosen for aerosol constituent yield analysis: the Eleaf iWü (Eleaf Group, Shenzhen, China) equipped with stock refillable pod containing 1.3 coil, Smok Nord 4 (Shenzhen IVPS Technology Co. Ltd., Shenzhen, China) equipped with Mouth to Lung RPM Mesh 0.4 coil, Uwell

Zumwalt (Shenzhen Uwell Technology Co. Ltd., Shenzhen, China) equipped with stock refillable pod containing 1.2 coil, and Vaporesso Renova ZERO (Shenzhen Vaporesso Technology Ltd., Shenzhen, China) with stock refillable pod containing 1.3 coil. For the Eleaf iWü and Uwell Zumwalt devices, power output was not adjustable. For the Smok Nord 4 and Vaporesso Renova Zero devices, power output was set to the medium, or middle, setting based on manufacturer range or coil maximum (Table 1).

The study was conducted post U.S. FDA 2020 enforcement policy on unauthorized flavored cartridge-based e-cigarettes (41), and therefore, tobacco-type and menthol-type e-liquid formulations were selected for each brand. Some devices (BIDI Stick and RELX) had sweet flavor e-liquid formulations available for sale, and thus, were included in the

study. All tested ENDS contained tobacco-derived nicotine except one manufacturer (Glas Inc.) which contained synthetic nicotine. All ENDS, except for JUUL products sourced internally from CAN, were purchased online, and shipped directly to the test facility or purchased directly by the test facility between March 2021 and July 2022. Sample analysis for each test method was completed within 2 months upon test facility product receipt. The test facility was responsible for ENDS product storage at room temperature in the commercial packaging until time of aerosol collection.

Consistent with test product selection criteria and the rationale for the use of tobacco-type and menthol-type e-liquid discussed above, two nicotine salt e-liquid formulations, one tobacco flavor, and one menthol flavor (Mr. Salt-E Tobacco and Mr. Salt-E Menthol 4.5% nicotine e-liquids, Chrystal Distribution, Lexington, KY, USA) were chosen for aerosol constituent yield analysis in open system devices. Manufacturers stated propylene glycol (PG):glycerol ratio of these e-liquids was 60:40. Information about purity and ingredients, including the type of organic acid used to produce the salt formulation of Mr. Salt-E Tobacco and Menthol Ice 4.5% nicotine e-liquids, were not readily available from the manufacturer or third-party retailers. In addition, Mr. Salt-E e-liquid has been used by other researchers and provided a nicotine strength and form similar to the majority of the closed system products, i.e., approximately 5% nicotine salt formulation (42). Note: information was gathered directly from consumer-facing media, including manufacturer website, retailer website, and/or any included product literature. For most products, the accuracy of specifications published on consumer-facing media was not verifiable by other means.

### 2.3 Cigarette comparator

For comparison of aerosol constituent values to combustible cigarette, CC smoke yields (normalized to nicotine) are provided for the University of Kentucky 1R6F reference cigarette (1R6F), a standard reference cigarette. The 1R6F is a traditional-style cellulose-acetate filtered king size cigarette with an American tobacco blend (flue-cured tobacco, Burley, and Oriental tobacco types, reconstituted tobacco, expanded flue-cured, expanded Burley, glycerol, Isosweet (sugar), PG) (43). Values used for comparisons were obtained: first, from the University of Kentucky 1R6F reference cigarette certificate of analysis (43); second, published literature (44, 45); and third, if no literature

values were available, internal study data generated by third party contract research organizations were used. Details regarding the specific values and references used for comparison between market ENDS and 1R6F CC smoke are provided in section 3.6 and [supplemental material](#).

### 2.4 Aerosol collection and characterization of HPHCs

Aerosol collection and constituent analyses (Table 2) were performed by Enthalpy Analytical LLC (Durham, NC, USA). Enthalpy Analytical LLC was accredited to the International Organization for Standardization (ISO) 17025 standard (46) at the time of the study. All test methods for chemical constituent analytical measurements were validated for the analysis of ENDS aerosol according to ICH guidance Q2 (R1) (47). Primary constituents, select carbonyls, select metals, and glycidol analysis in ENDS aerosol was conducted according to previously published methods (48). Additional method specifics (i.e., extract concentrations, internal standard concentrations, etc.) can be addressed by Enthalpy Analytical LLC upon request.

Briefly, ENDS aerosol was collected in a dedicated laboratory room in accordance with the ISO 20768 standard (49). Samples were stored under ambient conditions until analysis. Sample collection and puffing was carried out on a linear smoking machine (device orientation at -45 degrees from horizontal) with automated activation using a non-intense regime following ISO 20768 standard consisting of a 55-mL puff volume, a three-second puff duration, and two puffs per minute, and a custom intense regime consisting of a 110-mL puff volume, a six-second puff duration, and two puffs per minute. Both regimes used a square wave puff profile. Devices with adjustable airflow were configured to the maximum possible airflow. Devices with adjustable wattage were set to the medium level as discussed in Section 2.2. Under the intense puffing regime, some brands reached the end of their allowed coil activation duration before completing the six-second puff. Linear smoking machine settings were not adjusted since the maximum puff duration was taken from these devices.

To determine the useful life of the product and to minimize the contribution of dry puffs to the analytical results, an end of life (EOL) study was performed according to JAMESON *et. al* (48) to determine the number of machine puffs needed to completely deplete each tested product. Puffing EOL was determined under both ISO 20768 and intense puffing regimes with five replicates. Based on the EOL analysis, the number of puffs required to consume 85%

**Table 2. HPHCs and chemicals analyzed in ENDS aerosol.**

Classification of HPHCs and chemicals	Main text	Supplemental only
Primary constituents	Nicotine, propylene glycol (PG), glycerol, menthol	Water
Carbonyls	Acetaldehyde, acetyl propionyl, acrolein, <i>n</i> -butyraldehyde, crotonaldehyde, diacetyl, formaldehyde	NA
Metals	Chromium (Cr), copper (Cu), iron (Fe), lead (Pb), nickel (Ni), zinc (Zn)	Arsenic (As), beryllium (Be), cadmium (Cd), cobalt (Co), selenium (Se), silver (Ag), Tin (Sn)
Glycidol	Glycidol	NA

NA = not applicable

of the entire e-liquid was calculated and used for all aerosol collections for all aerosol constituents analyses to minimize contributions from dry puffing and characterize constituents that may change over the life of the entire pod. Separate aerosol samples were collected for primary constituents, carbonyls, metals, and glycidol. Each of the 35 unique test products, as shown in Table 1, were collected in five replicates and each replicate analyzed for primary constituents, carbonyls, metals, and glycidol. For glycidol analysis, select products required additional procurement at a later date in the study, and therefore, EOL was reconducted and values shown in tables may differ when compared to primary constituents, carbonyls, and metals.

### 2.5 Data analysis

Data were reported from the test facility on a per-puff basis. All presented data in tables provide the mean and standard deviation of all five replicates. A wide range of analyte yields were reported across the study by device and puffing conditions. No outliers were removed, and no single device repeats were performed for any products used in the study. For carbonyls and metals, several brands displayed much greater variability than other tested devices. The poor reproducibility observed in some devices may be related to specific design features of that device. When reported analyte measurements consisted of a mixture of replicate measurements both greater than the limit of quantitation (LOQ) and below the LOQ (BLOQ), the numerical mean analyte yield was computed and reported only if that mean yield exceeded LOQ. For constituent measurements BLOQ, the average of the LOQ and limit of detection (LOD) was used as the numerical value in the aforementioned computation. For constituent measurements below the limit of detection (BLOD), the numerical LOD divided by 2 was used as the numerical value. The aforementioned approach for imputation of values BLOD and BLOQ was conducted in a similar manner as described in MARGHAM *et. al* (38). Since values are reported on a per-puff basis and the number of puffs differ between ENDS, LODs and LOQs may differ slightly as shown in parentheses in the results section. See supplemental material for additional information regarding data analysis and ENDS specific LODs and LOQs.

For comparison to 1R6F CC smoke, ENDS analyte values were normalized on a per-mg of nicotine basis using Equation 1. See [supplemental material Tables S1 and S2](#) for specific values used for comparisons.

$$\frac{\text{Analyte Conc. (converted to mg)}}{1 \text{ puff}} \times \frac{\# \text{ of puffs}}{1 \text{ collection (85\% of EOL)}} \times \frac{1 \text{ collection (85\% of EOL)}}{\text{Nicotine Conc. (mg)}} = \text{Analyte Conc. (mg) per mg nicotine} \quad [1]$$

Values used for 1R6F CC smoke yields were converted to mg per mg nicotine in a similar fashion as shown in Equation 1 in which literature analyte values were converted to mg per stick then divided by mg of nicotine per stick. See [supplemental material Tables S3 and S4](#) for specific values used for comparisons. All data analysis was performed using basic statistical functions in Microsoft Excel.

## 3. RESULTS AND DISCUSSION

The following results and discussion are focused on providing a general discussion pertaining to the North American ENDS market at the time of testing and will not include comparisons of individual products to previously reported data in the vast ENDS literature that exist today. A complete review of the ENDS HPHC aerosol literature is out of the scope of this publication, but several literature reviews cover this area in detail (50–54).

### 3.1 Number of puffs and device mass loss (DML)

Number of puffs and DML per-puff values for market ENDS are presented at the top of each table. Puff count values shown in Tables 3 through 6 (and all tables shown in supplemental material) were based on EOL measurements and represent the number of puffs required to consume 85% of the available e-liquid in each tested product. For market ENDS, the number of puffs ranged from approximately 150 to 450 for ISO 20768 puff regime and 80 to 230 puffs for the intense puff regime. The aerosol delivery ranged from approximately 1.0 mg DML per puff to 15.0 mg DML per puff for ISO 20768 puff regime with a marked increase in aerosol mass per puff for the intense puff regime due to the larger puff volume and longer puff duration. As expected, DML per collection, shown in supplemental material, was proportional to the pod fill volume, while number of puffs (based on 85% of EOL) and DML per puff were brand specific. In general, closed system ENDS had lower DML per puff values than open system ENDS.

### 3.2 Primary constituents in ENDS aerosol

Market ENDS primary constituent (nicotine, PG, glycerol, menthol) yields per puff for aerosol collected via ISO 27068 and intense puffing regimes are presented in Table 3 (page 202) (see supplemental material for additional analysis of water). Data normalized per collection and per g DML are presented in [supplemental material \(Tables S7 and S8\)](#).

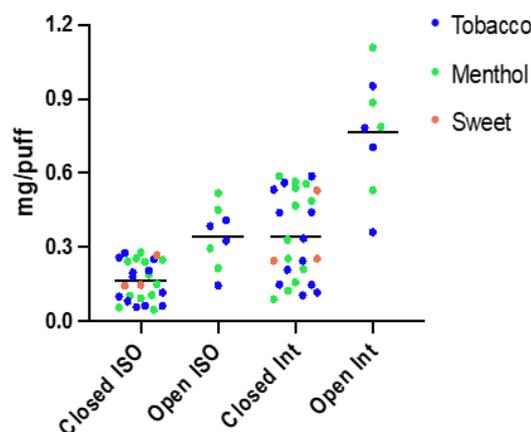


Figure 1. Nicotine aerosol yields for North American ENDS under ISO 20768 (ISO) and Intense (Int) puffing regimes.

Figure 1 depicts the nicotine per puff for closed and open system ENDS under the ISO 20768 and intense puffing regimes. Nicotine per puff ranged from approximately 0.04 to 0.28 mg/puff in closed system ENDS under ISO 20768 puffing and 0.14 to 0.52 mg/puff in open system ENDS. Open system nicotine yields are dependent on the nicotine content of the e-liquid chosen. The closed system ENDS produced between 12 and 82 mg of nicotine per collection while open systems ranged from 49 to 152 mg per refillable pod for the tested device and e-liquid combination irrespective of puffing regime.

For PG and glycerol, aerosol yields corresponded to e-liquid formulations ranging from approximately 70:30 to 30:70 (PG:Glycerol). Menthol aerosol yields for non-tobacco flavored ENDS ranged from 0.009 to 0.168 mg/puff for ISO 20768 and 0.013 to 0.337 mg/puff for intense puffing regime. Water aerosol yields ranged from 0.14 to 0.80 mg/puff for ISO 20768 and 0.23 to 1.53 mg/puff for intense collections.

### 3.3 Carbonyls in ENDS aerosol

Carbonyl formation has been a subject of particular interest within ENDS research due to their ability to form from primary aerosol constituents and known adverse impact on human health when inhaled at sufficient concentrations (55). Although the formation of carbonyls is well understood from a mechanistic standpoint, i.e., oxidation of primary ingredients PG and glycerol during heating and aerosolization, generation of carbonyls is dynamic in that device design, power, wicking rate, formulation, and coil temperature impact their aerosol yields (50).

Carbonyl yields per puff for ISO 20768 and intense aerosol collections for market ENDS are presented in Table 4 (page 205). Data normalized per collection and per g DML are presented in [supplemental material \(Tables S9 and S10\)](#). Formaldehyde yields ranged from 0.054 to 4.69  $\mu\text{g/puff}$  in closed system ENDS and 0.066 to 30.4  $\mu\text{g/puff}$  in open system ENDS under the ISO 20768 puffing regime while intense puffing ranged from 0.11 to 82.1  $\mu\text{g/puff}$  in closed system ENDS and 0.75 to 36.3  $\mu\text{g/puff}$  in open system ENDS.

Unlike primary ingredients, carbonyls were highly variable across the 35 ENDS tested. All products produced quantifiable levels of acetaldehyde, acrolein and formaldehyde, irrespective of puffing regime, while other carbonyl compounds were brand dependent. No correlation was observed between carbonyl yields and DML or puff count for the tested products. Specifically, the products with the highest DML yield (Smok Nord 4) and largest number of puffs (JUUL) yielded among the lowest levels of formaldehyde and other carbonyls, providing strong evidence that device characteristics, i.e., heater design and temperature control, drive carbonyl formation. This finding was consistent with published literature (56). For select brands, marked changes in carbonyl yields were observed between ISO 20768 and intense puffing regimes (e.g., myBlu and South Beach). One brand (RELX Classic) was tested with four different e-liquid flavors in which differences in carbonyl yields were observable on a per-g DML basis suggesting that while device design is the primary driver of carbonyl formation, e-liquid composition is also a contribu-

ting factor in determining yields of carbonyl compounds potentially due to differences in wicking between formulations. These findings were consistent with published literature (57, 58). Lastly, for one brand (Vuse Alto) the same flavor (Rich Tobacco) was analyzed for three different nicotine strengths (5.0%, 2.4% and 1.8%). For this brand, no correlation between nicotine concentration and carbonyl formation was observed.

### 3.4 Metals in ENDS aerosol

Unlike traditional cigarettes, ENDS devices are designed to operate below combustion temperatures and the transfer of metals, i.e., volatility, does not occur in the same manner (32). Metals in ENDS aerosol can be attributed to many different sources, and thus, device design plays a critical role in their overall yields.

Selected metal yields per puff for ISO 20768 and intense aerosol collections for market ENDS are presented in Table 5 (page 210). Additional metals and data normalized per collection and per g DML are presented in [supplemental material \(Tables S11 and S12\)](#).

Nickel aerosol yields on a per-puff basis showed nearly all ENDS aerosol contained quantifiable levels (31 out of 35, i.e., ISO 20768 or intense) above LOQ, ranging from BLOD to 61.0 ng/puff in closed system ENDS and 0.62 to 307 ng/puff in open system ENDS. In general, Cr, Cu, Fe, Ni, Pb, and Zn concentrations in aerosol were found to be highly variable ranging from BLOD to >30 ng/puff. Despite similar metal alloys used for heating elements in ENDS (34), not all tested products generated similar amounts of metals in aerosol. In particular, the open system products used identical e-liquid formulations and wide variations in metal yields were observable. Another observation was the use of a single brand (RELX Classic) with multiple flavor formulations yielded different levels of select metals in aerosol (e.g., Cu) as well. The results indicate that aerosol metals yields are a factor of both device design and e-liquid formulation which are consistent with published literature (34, 59). Additional metals were tested (As, Be, Cd, Co, Se, Ag) and are shown in supplemental material where all values were at or BLOQ for all tested products.

### 3.5 Glycidol in ENDS aerosol

Glycidol was initially reported in e-cigarettes by SLEIMAN *et al.* (60) in which formation was attributed to dehydration of glycerol, and later supported by others (61, 62). The glycidol values on a per-puff basis for ISO 20768 and intense aerosol collections for market ENDS are presented in Table 6 (page 215). For additional comparisons, per collection and per g DML data are presented in [supplemental material \(Tables S13 and S14\)](#).

Under the ISO 20768 puffing regime, glycidol aerosol yields ranged from 0.006 to 0.45  $\mu\text{g/puff}$  in closed system ENDS and 0.003 to 58.0  $\mu\text{g/puff}$  in open system ENDS. The total DML and total number of puffs do not correlate with the amount of glycidol generated in ENDS aerosol. In addition, glycerol per puff did not correlate with glycidol concentrations even though glycidol in ENDS aerosol is formed via the degradation of glycerol (62).

**Table 7. Comparison between ENDS ISO 20768 aerosol collection yields and 1R6F Reference CC ISO 3308 smoke values (per mg of nicotine).**

Constituent	ENDS category (mg/mg nicotine)			1R6F CC smoke (mg/mg nicotine)	ENDS category (% change)		
	ISO 20768			ISO 3308 Standard	Non-intense		
	Lowest	Mean	Highest	Mean	Lowest	Mean	Highest
Acetaldehyde	8.27E-05	3.28E-03	5.83E-02	7.24E-01	-99.99%	-99.5%	-92.0%
Acetyl Propionyl	7.23E-07	3.19E-05	3.39E-04	1.56E-02	-99.995%	-99.8%	-97.8%
Acrolein	8.66E-05	2.10E-03	1.26E-02	5.96E-02	-99.9%	-96.5%	-79.0%
<i>n</i> -Butyraldehyde	7.23E-07	2.69E-05	6.29E-04	3.47E-02	-99.998%	-99.9%	-98.2%
Crotonaldehyde	1.18E-06	2.41E-05	1.53E-04	1.41E-02	-99.99%	-99.8%	-98.9%
Diacetyl	7.43E-06	8.64E-05	1.09E-03	1.26E-01	-99.99%	-99.9%	-99.1%
Formaldehyde	1.53E-04	5.00E-03	9.36E-02	3.74E-02	-99.6%	-86.6%	150%
Arsenic	1.22E-07	5.35E-07	1.67E-06	3.35E-06	-96.4%	-84.0%	-50.2%
Cadmium	1.22E-08	2.71E-08	7.96E-08	5.08E-05	-99.98%	-99.9%	-99.8%
*Chromium	2.00E-07	1.11E-06	1.28E-05	2.49E-06	NC	NC	416%
Copper	3.88E-07	1.33E-05	1.55E-04	1.64E-05	-97.63%	-18.6%	848%
Lead	3.07E-08	7.07E-07	1.69E-05	1.63E-05	-99.81%	-95.7%	3.82%
*Nickel	2.00E-07	1.27E-05	1.23E-04	4.98E-06	NC	155%	2376%
Glycidol	9.09E-06	4.43E-04	8.20E-03	1.04E-03	-99.1%	-57.2%	691%

\* = Below limit of quantitation in 1R6F literature. Limit of quantitation was used for comparison to ENDS, refer to section 3.6.  
 NC = Not comparable. Both values below limits of quantitation.

**Table 8. Comparison between ENDS Intense aerosol collection yields and 1R6F Reference CC ISO 20778 Intense smoke values (per mg of nicotine).**

Constituent	END category (mg/m nicotine)			1R6F CC smoke (mg/mg nicotine)	ENDs category (% change)		
	Intense (110 mL, 6 s, 30 s)			ISO 20778 Intense	Intense		
	Lowest	Mean	Highest	Mean	Lowest	Mean	Highest
Acetaldehyde	1.66E-04	6.34E-03	1.60E-01	8.19E-01	-99.98%	-99.2%	-80.5%
Acetyl propionyl	5.69E-06	3.99E-05	3.67E-04	1.83E-02	-99.969%	-99.8%	-98.0%
Acrolein	1.21E-04	3.41E-03	5.02E-02	8.12E-02	-99.9%	-95.8%	-38.2%
<i>n</i> -Butyraldehyde	7.23E-07	3.67E-05	8.08E-04	3.55E-02	-99.998%	-99.9%	-97.7%
Crotonaldehyde	1.80E-06	3.89E-05	2.03E-04	2.69E-02	-99.99%	-99.9%	-99.2%
Diacetyl	2.59E-05	1.46E-04	2.00E-03	1.25E-01	-99.98%	-99.9%	-98.4%
Formaldehyde	2.17E-04	1.05E-02	3.37E-01	5.49E-02	-99.6%	-80.8%	514%
Arsenic	1.34E-07	4.22E-07	1.21E-06	3.50E-06	-96.2%	-87.9%	-65.5%
Cadmium	1.34E-08	2.73E-08	7.72E-08	4.96E-05	-99.97%	-99.9%	-99.8%
*Chromium	1.34E-07	1.07E-06	1.20E-05	2.49E-06	NC	NC	382%
Copper	5.09E-07	1.79E-05	7.23E-05	2.16E-05	-97.6%	-17.2%	235%
Lead	3.36E-08	1.20E-06	2.70E-05	1.62E-05	-99.8%	-92.6%	66.5%
*Nickel	2.50E-07	1.71E-05	1.04E-04	4.98E-06	NC	243%	1991%
Glycidol	1.22E-05	5.02E-04	9.26E-03	1.11E-03	-98.9%	-54.7%	736%

\* = Below limit of quantitation in 1R6F literature. Limit of quantitation was used for comparison to ENDS, refer to section 3.6.  
 NC = Not comparable. Both values below limits of quantitation.

### 3.6 ENDS vs. combustible cigarettes

Although a health risk assessment associated with the HPHCs reported in this work is out of the scope of this publication, the scientific evidence behind the reduction of toxic chemicals associated with ENDS aerosol compared to CC smoke has been previously demonstrated in the literature. Tables 7 and 8 show the percent change between tested HPHCs for the ENDS category aerosol collected using ISO 20768 and intense puffing regimes compared to

ISO 3308 and ISO 20778 1R6F CC smoke values obtained by multiple sources as described in the materials and methods, which are consistent with other 1R6F CC smoke values in the published literature (63).

For six out of the seven carbonyl compounds reported in this study, significant reductions in carbonyl compounds were observed in aerosol from ENDS, irrespective of puffing regime, when compared to 1R6F CC smoke. Formaldehyde was the only exception in which the lowest generating tested ENDS product showed a 99% reduction

and the highest generating ENDS tested showed a significant increase (>100%) when compared to 1R6F CC smoke values. In addition, ISO 20768 and intense puffing regimes showed observable differences in the mean and highest formaldehyde producing ENDS, illustrating that ENDS HPHC yields are specific to the device and formulation. A recent review article by SOULET AND SUSSMAN (51), evaluated numerous studies published after 2017 for the analysis of metals in ENDS aerosol and found that many lacked information regarding aerosol collection methods and tested devices, preventing impactful outcomes needed for appropriate health risk contextualization. In this study, standardized puffing conditions, aerosol collection, and validated methods allowed for critical quality control measures (i.e., background laboratory aerosol blanks) to be established providing the accuracy and precision needed to quantify ENDS aerosol metals at low levels. ENDS aerosol nickel yields were quantifiable (>LOQ in at least one puffing regime) in 23 of 27 closed system products and all eight open system products. Chromium was quantifiable in eight of 27 closed system products and five of eight open system products (Table 5). ENDS may utilize metals in the device components (e.g., Ni and Cr) while 1R6F CC smoke values for Ni and Cr remain below limits of detection and quantitation (44, 45, 63). In order to perform percent change calculations, LOQ values for Ni (10.0 ng/cig) and Cr (5.0 ng/cig) reported in HASHIZUME *et al.* (45) for ISO 20778 intense 1R6F smoke values were used for comparison, consistent with other reported limits in literature (21). Some ENDS yielded low levels of Ni and Cr in aerosol below 1R6F CC smoke LOQ, however, several products had considerably higher aerosol yields than 1R6F CC smoke. Similarly, mean values for both Cu and Pb were reduced in most ENDS aerosol when compared to 1R6F CC smoke, but certain products produced Cu and Pb yields considerably above levels reported in 1R6F CC smoke. These observations were consistent with previously published literature (64).

To date, minimal data exist on CC smoke glycidol yields due to its absence on the FDAs established list of 93 HPHCs (65). With the proposed addition of glycidol to the established HPHC list (66), limited comparisons between product categories exist. The comparison between ENDS aerosol and 1R6F CC smoke in the current study is unique in that the glycidol yields for 1R6F CC smoke were determined in the same test facility utilizing the same analytical method. Similar to formaldehyde, the mean and lowest yielding glycidol ENDS remain significantly reduced when compared to 1R6F CC smoke. However, the highest glycidol yielding ENDS produce nicotine normalized yields exceeding 1R6F CC smoke.

Considered holistically, ENDS aerosol shows dramatic reductions in HPHC yields compared to 1R6F CC smoke. As discussed above, not all market ENDS generate equivalent levels of HPHCs. With respect to certain individual toxic metals and carbonyl compounds, the yields differed by several orders of magnitude between the lowest and highest HPHC yielding market ENDS, some approached or exceeded 1R6F CC smoke yields.

### 3.7 Limitations

The current work is intended to provide a comprehensive overview of select HPHCs and other chemicals quantitatively determined using both regimens, ISO 20768 and intense puffing, to collect aerosol for market ENDS reflective of North America in 2021 and 2022. The analyses were performed by an ISO accredited laboratory using validated analytical methods designed to provide a head-to-head comparative study. Currently, no standardized intense puffing regime exists. Intense puffing conditions were chosen to study HPHC yields under exaggerated conditions that may not be representative of typical product usage. Without consumer behavior data for each product toxicological health risk assessments were out of scope of the study.

HPHC yields have been shown previously to vary over pod life (44). However, ENDS may suffer from elevated HPHCs when depletion of the pod is approached (67). To collect a representative sample of product aerosol with standardized methodology, while minimizing the collection of dry puffs since consumer behavior suggests that ENDS users do not repeatedly dry-puff due to the off-putting taste (68), aerosol was collected using an 85% EOL approach. The goal of this study aimed at providing comparisons under standardized conditions and was not designed to provide values representative of specific use scenarios such as end of pod life that may result in dry puffing. Despite efforts to minimize dry puffing, high standard deviations for carbonyl yields for select products may indicate individual replicates experienced one or more dry puffs during aerosol collection.

The authors state in the materials and methods that all devices and e-liquid formulations were bought commercially and handled only by the test facility; and the authors do not have information regarding the product age or storage conditions prior to purchasing. The aerosol collections for the open system ENDS presented in this work use one brand of e-liquid (Mr. Salt-E), and any future reference to the study data should be appropriately contextualized. In addition, the open system ENDS aerosol collections were performed using a brand-new refillable pod with fresh e-liquid, i.e., recently removed from the commercial packaging, however, the current work does not provide any data regarding HPHC yields post first fill and first use. Therefore, future work should evaluate the HPHC yields after first fill and first use to provide HPHC yields over the course of the refillable pod life as repetitive use may lead to a change in HPHC aerosol yields.

Lastly, it is worth acknowledging that while conducting the study in 2021 and 2022 several changes occurred in the market and regulatory environment in North America. First, the U.S. ENDS market shifted significantly from 2020 to 2022 towards illegally imported disposable flavored ENDS (69). Future studies may want to include such products while they remain accessible despite regulatory efforts to combat importation and retail of illicit products. In Canada, the Nicotine Concentration in Vaping Products Regulations (NCVPR) established a maximum nicotine concentration of 20 mg/mL (~2.0% wt.) for vaping products manufactured or imported for sale (70), and therefore, the vast number of tested ENDS in this study are now no longer available in

that market. In summary, although the selected ENDS in the present study may not be representative of the 2024 consumer market, it does provide a critical snapshot in time to help multiple stakeholders, in industry, regulatory bodies, and academia, track the change in ENDS over time with respect to HPHC yields.

#### 4. CONCLUSION

To date, the following study is one of the most comprehensive analyses of select HPHCs in ENDS aerosol using validated analytical methods in the same test facility for a head-to-head comparison. The most notable outcome of this study was that the ENDS product landscape is highly varied in product characteristics, and that device design and e-liquid formulations are critical to minimize the yields of select carbonyls, metals, and glycidol generated in aerosol. The reported dataset contains multiple e-liquid formulations tested in the same device, and multiple devices (i.e., open systems) with identical e-liquids. Both of which resulted in varied HPHC yields. Importantly, in corroboration with previous studies relating to individual ENDS, the North American ENDS market as a whole represents a significant reduction in total HPHC yields compared to 1R6F CC, when normalized to milligrams per nicotine. However, some ENDS produced yields of certain individual HPHCs that exceeded 1R6F CC while other ENDS yielded reductions greater than 99%. This variation across the ENDS product landscape highlights the need for appropriate regulatory standards to ensure consumers understand the risks associated with use of a particular product or product category. At present the tobacco-flavored formulations of two devices in this study (NJOY ACE & Vuse Solo) have received marketing granted orders (MGOs) from the U.S. FDA (71). The current study provides a critical comparison of these and other products existing in the North American ENDS market based on commercial availability between 2021 and 2022.

#### 5. CONFLICT OF INTEREST

All authors listed were employed by Juul Labs, Inc. at the time of the study. All testing was performed at Enthalpy Analytical LLC, now formally known as McKinney Specialty Labs LLC, and paid for in full by Juul Labs, Inc.

#### 6. AUTHOR CONTRIBUTIONS

Authorship (writing, review, editing, etc.) – CRS, IGG, JBJ, CJ; Data Analysis – JW, AB, SU, CJ, KC; Project Administration – DC, KC; Resources – IGG.

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#### 8. REFERENCES

1. Counts, M.E., F.S. Hsu, and F.J. Tewes: Development of a Commercial Cigarette “Market Map” Comparison Methodology for Evaluating New or Non-Conventional Cigarettes; *Regul. Toxicol. Pharmacol.* 46 (2006) 225–242. DOI: 10.1016/j.yrtph.2006.07.002
2. Jain, V., A. Alcheva, D. Huang, R. Caruso, A. Jain, M. Lay, R. O’Connor, and I. Stepanov: Comprehensive Chemical Characterization of Natural American Spirit Cigarettes; *Tob. Regul. Sci.* 5 (2019) 381–399. DOI: 10.18001/trs.5.4.8
3. Roemer, E., R. Dempsey, and M.K. Schorp: Toxicological Assessment of Kretek Cigarettes: Part 1: Background, Assessment Approach, and Summary of Findings; *Regul. Toxicol. Pharmacol.* 70 Suppl 1 (2014) S2–14. DOI: 10.1016/j.yrtph.2014.11.015
4. Morton, M.J. and S.W. Laffoon: Cigarette Smoke Chemistry Market Maps under Massachusetts Department of Public Health Smoking Conditions; *Regul. Toxicol. Pharmacol.* 51 (2008) 1–30. DOI: 10.1016/j.yrtph.2008.03.001
5. Jablonski, J.J., J.H. Maines, A.G. Cheetham, and I.G. Gillman: Comparative Levels of Carbonyl Delivery Between Mass-Market Cigars and Cigarettes; *Regul. Toxicol. Pharmacol.* 108 (2019) DOI: 10.1016/j.yrtph.2019.104453
6. Chepiga, T.A., M.J. Morton, P.A. Murphy, J.T. Avalos, B.R. Bombick, D.J. Doolittle, M.F. Borgerding, and J.E. Swauger: A Comparison of the Mainstream Smoke Chemistry and Mutagenicity of a Representative Sample of the US Cigarette Market with Two Kentucky Reference Cigarettes (K1r4f and K1r5f); *Food Chem. Toxicol.* 38 (2000) 949–962. DOI: 10.1016/s0278-6915(00)00086-7
7. Counts, M.E., F.S. Hsu, S.W. Laffoon, R.W. Dwyer, and R.H. Cox: Mainstream Smoke Constituent Yields and Predicting Relationships from a Worldwide Market Sample of Cigarette Brands: ISO Smoking Conditions; *Regul. Toxicol. Pharmacol.* 39 (2004) 111–134. DOI: 10.1016/j.yrtph.2003.12.005
8. Eldridge, A., T.R. Betson, M.V. Gama, and K. McAdam: Variation in Tobacco and Mainstream Smoke Toxicant Yields from Selected Commercial Cigarette Products; *Regul. Toxicol. Pharmacol.* 71 (2015) 409–427. DOI: 10.1016/j.yrtph.2015.01.006
9. Carmines, E. and G. Gillman: Comparison of the Yield of Very Low Nicotine Content Cigarettes to the Top 100 United States Brand Styles; *Beitr. Tabakforsch. Int.* 28 (2019) 253–266. DOI: 10.2478/cttr-2019-0005
10. Piadé, J.-J., S. Wajrock, G. Jaccard, and G. Janeke: Formation of Mainstream Cigarette Smoke Constituents Prioritized by the World Health Organization - Yield Patterns Observed in Market Surveys, Clustering and Inverse Correlations; *Food Chem. Toxicol.* 55 (2013) 329–347. DOI: 10.1016/j.fct.2013.01.016
11. Pazo, D.Y., F. Moliere, M.M. Sampson, C.M. Reese, K.A. Agnew-Heard, M.J. Walters, M.R. Holman, B.C. Blount, C.H. Watson, and D.M. Chambers: Mainstream Smoke Levels of Volatile Organic Compounds in 50 US Domestic Cigarette Brands Smoked with the ISO and Canadian Intense Protocols; *Nicotine Tob. Res.* 18

- (2016) 1886–1894. DOI: 10.1093/ntr/ntw118
12. Edwards, S.H., L.M. Rossiter, K.M. Taylor, M.R. Holman, L. Zhang, Y.S. Ding, and C.H. Watson: Tobacco-Specific Nitrosamines in the Tobacco and Mainstream Smoke of U.S. Commercial Cigarettes; *Chem. Res. Toxicol.* 30 (2017) 540–551. DOI: 10.1021/acs.chemrestox.6b00268
  13. Vu, A.T., K.M. Taylor, M.R. Holman, Y.S. Ding, B. Hearn, and C.H. Watson: Polycyclic Aromatic Hydrocarbons in the Mainstream Smoke of Popular U.S. Cigarettes; *Chem. Res. Toxicol.* 28 (2015) 1616–1626. DOI: 10.1021/acs.chemrestox.5b00190
  14. Oldham, M.J., D.J. DeSoi, L.T. Rimmer, K.A. Wagner, and M.J. Morton: Insights from Analysis for Harmful and Potentially Harmful Constituents (HPHCs) in Tobacco Products; *Regul. Toxicol. Pharmacol.* 70 (2014) 138–148. DOI: 10.1016/j.yrtph.2014.06.017
  15. Tobacco Journal International: Reference Products Used in Tobacco and Smoke Analyses; *Tob. J. Int.* 2 (2013) 150–154. Available at: <https://www.coresta.org/sites/default/files/pages/tji0213-p150-154-ref-products.pdf>
  16. Roemer, E., H. Schramke, H. Weiler, A. Buettner, S. Kausche, S. Weber, A. Berges, M. Stueber, M. Muench, E. Trelles-Sticken, J. Pype, K. Kohlgrueber, H. Voelkel, and S. Wittke: Mainstream Smoke Chemistry and *in Vitro* and *in Vivo* Toxicity of the Reference Cigarettes 3R4F and 2R4F; *Beitr. Tabakforsch. Int.* 25 (2012) 316–335. DOI: 10.2478/cttr-2013-0912
  17. Wagner, K.A., R. Higby, and K. Stutt: Puff-by-Puff Analysis of Selected Mainstream Smoke Constituents in The Kentucky Reference 2R4F Cigarette; *Beitr. Tabakforsch. Int.* 21 (2005) 273–279. DOI: 10.2478/cttr-2013-0793
  18. Benowitz, N.L. and M.L. Goniewicz: The Regulatory Challenge of Electronic Cigarettes; *JAMA* 310 (2013) 685–686. DOI: 10.1001/jama.2013.109501.
  19. Reilly, S.M., T. Cheng, and J. DuMond: Method Validation Approaches for Analysis of Constituents in ENDS; *Tob. Regul. Sci.* 6 (2020) 242–265. DOI: 10.18001/trs.6.4.3
  20. Williams, M. and P. Talbot: Design Features in Multiple Generations of Electronic Cigarette Atomizers; *Int. J. Environ. Res. Public Health* 16 (2019) 2904. DOI: 10.3390/ijerph16162904
  21. Cunningham, A., K. McAdam, J. Thissen, and H. Digard: The Evolving E-Cigarette: Comparative Chemical Analyses of E-Cigarette Vapor and Cigarette Smoke; *Front. Toxicol.* 2 (2020) DOI: 10.3389/ftox.2020.586674
  22. Belushkin, M., D.T. Djoko, M. Esposito, A. Korneliou, C. Jeannet, M. Lazzarini, and G. Jaccard: Selected Harmful and Potentially Harmful Constituents Levels in Commercial E-Cigarettes; *Chem. Res. Toxicol.* 33 (2020) 657–668. DOI: 10.1021/acs.chemrestox.9b00470
  23. Uchiyama, S., K. Ohta, Y. Inaba, and N. Kunugita: Determination of Carbonyl Compounds Generated from the E-Cigarette Using Coupled Silica Cartridges Impregnated with Hydroquinone and 2,4-Dinitrophenylhydrazine, Followed by High-Performance Liquid Chromatography; *Anal. Sci.* 29 (2013) 1219–1222. DOI: 10.2116/analsci.29.1219
  24. Goniewicz, M.L., J. Knysak, M. Gawron, L. Kosmider, A. Sobczak, J. Kurek, A. Prokopowicz, M. Jablonska-Czapla, C. Rosik-Dulewska, C. Havel, P. Jacob III, and N. Benowitz: Levels of Selected Carcinogens and Toxicants in Vapour from Electronic Cigarettes; *Tob. Control* 23 (2014) 133–139. DOI: 10.1136/tobaccocontrol-2012-050859
  25. Laugesen, M.: Nicotine and Toxicant Yield Ratings of Electronic Cigarette Brands in New Zealand; *N. Z. Med. J.* 128 (2015) 77–82. PMID: 25820506
  26. Uchiyama, S., Y. Senoo, H. Hayashida, Y. Inaba, H. Nakagome, and N. Kunugita: Determination of Chemical Compounds Generated from Second-Generation E-Cigarettes Using a Sorbent Cartridge Followed by a Two-Step Elution Method; *Anal. Sci.* 32 (2016) 549–555. DOI: 10.2116/analsci.32.549
  27. El-Hellani, A., R. Salman, R. El-Hage, S. Talih, N. Malek, R. Baalbaki, N. Karaoghlanian, R. Nakkash, A. Shihadeh, and N.A. Saliba: Nicotine and Carbonyl Emissions from Popular Electronic Cigarette Products: Correlation to Liquid Composition and Design Characteristics; *Nicotine Tob. Res.* 20 (2018) 215–223. DOI: 10.1093/ntr/ntw280
  28. Klager, S., J. Vallarino, P. MacNaughton, D.C. Christiani, Q. Lu, and J.G. Allen: Flavoring Chemicals and Aldehydes in E-Cigarette Emissions; *Environ. Sci. Technol.* 51 (2017) 10806–10813. DOI: 10.1021/acs.est.7b02205
  29. Williams, M., K. Bozhilov, S. Ghai, and P. Talbot: Elements Including Metals in the Atomizer and Aerosol of Disposable Electronic Cigarettes and Electronic Hookahs; *PLoS One* 12 (2017) e0175430. DOI: 10.1371/journal.pone.0175430
  30. Olmedo, P., W. Goessler, S. Tanda, M. Grau-Perez, S. Jarmul, A. Aherrera, R. Chen, M. Hilpert, J.E. Cohen, A. Navas-Acien, and A.M. Rule: Metal Concentrations in E-Cigarette Liquid and Aerosol Samples: The Contribution of Metallic Coils; *Environ. Health Perspect.* 126 (2018) 027010. DOI: 10.1289/EHP2175
  31. Zhao, D., A. Navas-Acien, V. Ilievski, V. Slavkovich, P. Olmedo, B. Adria-Mora, A. Domingo-Relloso, A. Aherrera, N.J. Kleiman, A.M. Rule, and M. Hilpert: Metal Concentrations in Electronic Cigarette Aerosol: Effect of Open-System and Closed-System Devices and Power Settings; *Environ. Res.* 174 (2019) 125–134. DOI: 10.1016/j.envres.2019.04.003
  32. Halstead, M., N. Gray, N. Gonzalez-Jimenez, M. Fresquez, L. Valentin-Blasini, C. Watson, and R.S. Pappas: Analysis of Toxic Metals in Electronic Cigarette Aerosols Using a Novel Trap Design; *J. Anal. Toxicol.* 44 (2020) 149–155. DOI: 10.1093/jat/bkz078
  33. Gray, N., M. Halstead, L. Valentin-Blasini, C. Watson, and R.S. Pappas: Toxic Metals in Liquid and Aerosol from Pod-Type Electronic Cigarettes; *J. Anal. Toxicol.* 46 (2022) 69–75. DOI: 10.1093/jat/bkaa185
  34. Aherrera, A., J.J. Lin, R. Chen, M. Tehrani, A. Schultze, A. Borole, S. Tanda, W. Goessler, and A.M. Rule: Metal Concentrations in E-Cigarette Aerosol Samples: A Comparison by Device Type and Flavor; *Environ. Health Perspect.* 131 (2023) 127004. DOI: 10.1289/ehp11921

35. Chen, X., P.C. Bailey, C. Yang, B. Hiraki, M.J. Oldham, and I.G. Gillman: Targeted Characterization of the Chemical Composition of JUUL Systems Aerosol and Comparison with 3R4F Reference Cigarettes and IQOS Heat Sticks; *Separations* 8 (2021) 168. DOI: 10.3390/separations8100168
36. Margham, J., K. McAdam, A. Cunningham, A. Porter, S. Fiebelkorn, D. Mariner, H. Digard, and C. Proctor: The Chemical Complexity of E-Cigarette Aerosols Compared with the Smoke from a Tobacco Burning Cigarette; *Front. Chem.* 9 (2021). DOI: 10.3389/fchem.2021.743060
37. Tayyarah, R. and G.A. Long: Comparison of Select Analytes in Aerosol from E-Cigarettes with Smoke from Conventional Cigarettes and with Ambient Air; *Regul. Toxicol. Pharmacol.* 70 (2014) 704–710. DOI: 10.1016/j.yrtph.2014.10.010.
38. Margham, J., K. McAdam, M. Forster, C. Liu, C. Wright, D. Mariner, and C. Proctor: Chemical Composition of Aerosol from an E-Cigarette: A Quantitative Comparison with Cigarette Smoke; *Chem. Res. Toxicol.* 29 (2016) 1662–1678. DOI: 10.1021/acs.chemrestox.6b00188
39. Cook, D.K., G. Lalonde, M.J. Oldham, J. Wang, A. Bates, S. Ullah, C. Sulaiman, K. Carter, C. Jongasma, G. Dull, and G. Gillman: A Practical Framework for Novel Electronic Nicotine Delivery System Evaluation: Chemical and Toxicological Characterization of JUUL2 Aerosol and Comparison with Reference Cigarettes; *Toxics* 12 (2024) 41. DOI: 10.3390/toxics12010041
40. Office of the President of Mexico, Modification to Law on General Taxes on Imports and Exports - Tariff section 3824.90.83, 8453.70.18, and 8453.90.03. 2020, Official Journal of the Federation. Available at: [https://www.dof.gob.mx/nota\\_detalle.php?codigo=5653845&fecha=31/05/2022#gsc.tab=0](https://www.dof.gob.mx/nota_detalle.php?codigo=5653845&fecha=31/05/2022#gsc.tab=0)
41. U.S. Food and Drug Administration (FDA): FDA Finalizes Enforcement Policy on Unauthorized Flavored Cartridge-Based E-Cigarettes that Appeal to Children, Including Fruit and Mint; FDA, Silver Springs, MD, USA, 2020.
42. Harvanko, A.M., C.M. Havel, P. Jacob III, and N.L. Benowitz: Characterization of Nicotine Salts in 23 Electronic Cigarette Refill Liquids; *Nicotine Tob. Res.* 22 (2020) 1239–1243. DOI: 10.1093/ntr/ntz232
43. University of Kentucky: Certificate of Analysis for 1R6F Certified Reference Cigarette; University of Kentucky, College of Agriculture, Food, and Environment, Center for Tobacco Reference Products, Lexington, KY, USA, 2018. Available at: [https://ctpr.uky.edu/assets/pdf/webdocs/CoA18\\_1R6F.pdf](https://ctpr.uky.edu/assets/pdf/webdocs/CoA18_1R6F.pdf) (accessed August 2024)
44. Sakai, Y., S. Mori, M. Yanagimachi, T. Takahashi, K. Shibuya, A. Kumagai, S. Ishikawa, S. Ito, and T. Fukushima: Inter-Laboratory Reproducibility and Interchangeability of 3R4F and 1r6f Reference Cigarettes in Mainstream Smoke Chemical Analysis and in Vitro Toxicity Assays; *Beitr. Tabakforsch. Int.* 29 (2020) 119–135. DOI: 10.2478/cttr-2020-0011
45. Hashizume, T., S. Ishikawa, K. Matsumura, S. Ito, and T. Fukushima: Chemical and in vitro Toxicological Comparison of Emissions from a Heated Tobacco Product and the 1R6F Reference Cigarette; *Toxicol. Rep.* 10 (2023) 281–292. DOI: 10.1016/j.toxrep.2023.02.005
46. International Organization for Standardization (ISO): ISO/IEC 17025:2017. General Requirements for the Competence of Testing and Calibration Laboratories; ISO, Geneva, Switzerland, 2017.
47. International Conference on Harmonisation (ICH): Validation of Analytical Procedures: Text and Methodology Q2(R1); ICH Harmonised Tripartite Guideline, 2005. Step 4.
48. Jameson, J.B., J. Wang, P.C. Bailey, M.J. Oldham, C.R. Smith, L.N. Jeong, D.K. Cook, A.L. Bates, S. Ullah, A.S.C. Pennington, and I.G. Gillman: Determination of Chemical Constituent Yields in E-Cigarette Aerosol Using Partial and Whole Pod Collections, a Comparative Analysis; *Front. Chem.* 11 (2023) 1223967. DOI: 10.3389/fchem.2023.1223967
49. International Organization for Standardization (ISO): ISO 20768:2018 - Vapour Products — Routine Analytical Vaping Machine — Definitions and Standard Conditions; ISO, Geneva, Switzerland, 2018.
50. Farsalinos, K.E. and G. Gillman: Carbonyl Emissions in E-Cigarette Aerosol: A Systematic Review and Methodological Considerations; *Front. Physiol.* 8 (2017) 1119. DOI: 10.3389/fphys.2017.01119
51. Soulet, S. and R.A. Sussman: A Critical Review of Recent Literature on Metal Contents in E-Cigarette Aerosol; *Toxics* 10 (2022) 510. DOI: 10.3390/toxics10090510
52. Soulet, S. and R.A. Sussman: Critical Review of the Recent Literature on Organic Byproducts in E-Cigarette Aerosol Emissions; *Toxics* 10 (2022) 714. DOI: 10.3390/toxics10120714
53. Travis, N., M. Knoll, S. Cook, H. Oh, C.J. Cadham, L.M. Sanchez-Romero, and D.T. Levy: Chemical Profiles and Toxicity of Electronic Cigarettes: An Umbrella Review and Methodological Considerations; *Int. J. Environ. Res. Public Health* 20 (2023) 1908. DOI: 10.3390/ijerph20031908
54. Eshraghian, E.A. and W.K. Al-Delaimy: A Review of Constituents Identified in E-Cigarette Liquids and Aerosols; *Tob. Prev. Cessat.* 7 (2021) 10. DOI: 10.18332/tpc/131111
55. Geiss, O., I. Bianchi, and J. Barrero-Moreno: Correlation of Volatile Carbonyl Yields Emitted by E-Cigarettes with the Temperature of the Heating Coil and the Perceived Sensorial Quality of the Generated Vapours; *Int. J. Hyg. Environ. Health* 219 (2016) 268–277. DOI: 10.1016/j.ijheh.2016.01.004
56. Talih, S., R. Salman, N. Karaoghlanian, A. El-Hellani, and A. Shihadeh: Carbonyl Emissions and Heating Temperatures across 75 Nominally Identical Electronic Nicotine Delivery System Products: Do Manufacturing Variations Drive Pulmonary Toxicant Exposure?; *Chem. Res. Toxicol.* 36 (2023) 342–346. DOI: 10.1021/acs.chemrestox.2c00391
57. Li, Y., A.E. Burns, L.N. Tran, K.A. Abellar, M. Poindexter, X. Li, A.K. Madl, K.E. Pinkerton, and T.B. Nguyen: Impact of E-Liquid Composition, Coil Temperature, and Puff Topography on the Aerosol Chemistry of Electronic Cigarettes; *Chem. Res. Toxicol.* 34

- (2021) 1640–1654.  
DOI: 10.1021/acs.chemrestox.1c00070
58. Berg, C.J., D. Boyd Barr, E. Stratton, C. Escoffery, and M. Kegler: Attitudes Toward E-Cigarettes, Reasons for Initiating E-Cigarette Use, and Changes in Smoking Behavior After Initiation: A Pilot Longitudinal Study of Regular Cigarette Smokers; *Open J. Prev. Med.* 4 (2014) 789–800. DOI: 10.4236/ojpm.2014.410089.
  59. Zhao, D., V. Ilievski, V. Slavkovich, P. Olmedo, A. Domingo-Relloso, A.M. Rule, N.J. Kleiman, A. Navas-Acien, and M. Hilpert: Effects of E-Liquid Flavor, Nicotine Content, and Puff Duration on Metal Emissions from Electronic Cigarettes; *Environ. Res.* 204 (2022) 112270. DOI: 10.1016/j.envres.2021.112270
  60. Sleiman, M., J.M. Logue, V.N. Montesinos, M.L. Russell, M.I. Litter, L.A. Gundel, and H. Destaillets: Emissions from Electronic Cigarettes: Key Parameters Affecting the Release of Harmful Chemicals; *Environ. Sci. Technol.* 50 (2016) 9644–9651.  
DOI: 10.1021/acs.est.6b01741
  61. Jensen, R.P., R.M. Strongin, and D.H. Peyton: Solvent Chemistry in the Electronic Cigarette Reaction Vessel; *Sci. Rep.* 7 (2017) 42549. DOI: 10.1038/srep42549
  62. Uchiyama, S., M. Noguchi, A. Sato, M. Ishitsuka, Y. Inaba, and N. Kunugita: Determination of Thermal Decomposition Products Generated from E-Cigarettes; *Chem. Res. Toxicol.* 33 (2020) 576–583.  
DOI: 10.1021/acs.chemrestox.9b00410
  63. Jaccard, G., D.T. Djoko, A. Korneliou, R. Stabbert, M. Belushkin, and M. Esposito: Mainstream Smoke Constituents and in Vitro Toxicity Comparative Analysis of 3R4F and 1R6F Reference Cigarettes; *Toxicol. Rep.* 6 (2019) 222–231.  
DOI: 10.1016/j.toxrep.2019.02.009
  64. Pappas, R.S., N. Gray, M. Halstead, and C.H. Watson: Lactic Acid Salts of Nicotine Potentiate the Transfer of Toxic Metals into Electronic Cigarette Aerosols; *Toxics* 12 (2024) 65. DOI: 10.3390/toxics12010065
  65. U.S. Department of Health and Human Services (DHHS), Food and Drug Administration (FDA), Center for Tobacco Products (CTP): Guidance for Industry. Reporting Harmful and Potentially Harmful Constituents in Tobacco Products and Tobacco Smoke under Section 904(a)(3) of the Federal Food, Drug, and Cosmetic Act. Draft Guidance; DHHS, Silver Spring, MD, USA, 2012, 10 pp.
  66. U.S. Department of Health and Human Services (DHHS) and Food and Drug Administration (FDA): Harmful and Potentially Harmful Constituents in Tobacco Products; Established List; Proposed Additions; Request for Comments; FDA, Rockville, MD, USA, 2019, pp. 38032–38035. 84 FR 38032
  67. Farsalinos, K.E., V. Voudris, and K. Poulas: E-Cigarettes Generate High Levels of Aldehydes Only in ‘Dry Puff’ Conditions; *Addiction* 110 (2015) 1352–1356.  
DOI: 10.1111/add.12942
  68. Visser, W.F., E.J.Z. Krüsemann, W.N.M. Klerx, K. Boer, N. Weibolt, and R. Talhout: Improving the Analysis of E-Cigarette Emissions: Detecting Human ‘Dry Puff’ Conditions in a Laboratory as Validated by a Panel of Experienced Vapers; *Int. J. Environ. Res. Public Health* 18 (2021) 11520.  
DOI: 10.3390/ijerph182111520
  69. Ali, F.R.M., A.B. Seidenberg, E. Crane, E. Seaman, M.A. Tynan, and K. Marynak: E-Cigarette Unit Sales by Product and Flavor Type, and Top-Selling Brands, United States, 2020–2022; *MMWR Morb. Mortal. Wkly. Rep.* 72 (2023) 672–677.  
DOI: 10.15585/mmwr.mm7225a1
  70. Health Canada: Regulating Tobacco and Vaping Products: Vaping Products Regulations; Health Canada, 2024, Available at: <https://www.canada.ca/en/health-canada/services/smoking-tobacco/vaping/product-safety-regulation.html>
  71. U.S. Food and Drug Administration (FDA): Premarket Tobacco Product Marketing Granted Orders; FDA, Silver Spring, MD, USA, 2024. Available at: <https://www.fda.gov/tobacco-products/premarket-tobacco-product-applications/premarket-tobacco-product-marketing-granted-orders>

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## 9. SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found at: <https://sciendo.com/article/10.2478/cttr-2024-0008>.

## 10. DATA AVAILABILITY

The data supporting the conclusion may be made available upon request and appropriate legal review.

**Table 3. Market ENDS HPHCs and chemicals in aerosol – primary constituents (per puff).**

Parameter/constituent	Rich Tobacco	Classic Tobacco	Tobacco	Golden Tobacco	Rich Tobacco	Rich Tobacco	Rich Tobacco	Classic Tobacco
	2.40%	5.00%	4.80%	5.00%	5.00%	2.40%	1.80%	5.00%
	MyBlu	ACE	Solo	JUUL	Alto	Alto	Alto	RELX
<b>Primary constituents</b>								
ISO 20768 puff count	262	360	156	371	363	339	355	297
Intense puff count	104	213	114	229	140	167	190	140
Device mass loss (mg)								
ISO 20768	6.08 ± 0.18	4.62 ± 0.38	2.46 ± 0.19	1.30 ± 0.12	4.07 ± 0.58	3.75 ± 0.76	3.51 ± 0.89	6.58 ± 0.29
Intense	14.01 ± 1.39	7.97 ± 0.33	3.73 ± 0.12	2.21 ± 0.38	9.88 ± 0.96	9.07 ± 0.94	9.44 ± 0.95	12.78 ± 1.19
Nicotine (mg)								
ISO 20768	0.114 ± 0.005	0.196 ± 0.017	0.097 ± 0.011	0.061 ± 0.006	0.178 ± 0.024	0.079 ± 0.02	0.055 ± 0.021	0.276 ± 0.011
Intense	0.244 ± 0.019	0.333 ± 0.035	0.147 ± 0.006	0.100 ± 0.019	0.440 ± 0.026	0.206 ± 0.027	0.150 ± 0.018	0.532 ± 0.054
Propylene glycol (mg)								
ISO 20768	1.99 ± 0.19	1.31 ± 0.12	0.345 ± 0.042	0.301 ± 0.027	1.31 ± 0.20	1.34 ± 0.32	1.27 ± 0.47	1.21 ± 0.06
Intense	4.37 ± 0.39	2.15 ± 0.23	0.53 ± 0.02	0.53 ± 0.10	3.22 ± 0.20	3.58 ± 0.44	3.38 ± 0.34	2.40 ± 0.25
Glycerol (mg)								
ISO 20768	2.89 ± 0.13	1.92 ± 0.17	1.39 ± 0.16	0.79 ± 0.07	1.73 ± 0.20	1.71 ± 0.33	1.62 ± 0.46	3.32 ± 0.13
Intense	6.14 ± 0.58	3.32 ± 0.34	2.05 ± 0.08	1.33 ± 0.25	4.38 ± 0.28	4.27 ± 0.42	4.27 ± 0.42	6.55 ± 0.51

Parameter/constituent	Original Blend	Signature Tobacco	Classic	Tobacco	Mr. Salt-E Tobacco			
	5.00%	5.00%	6.00%	2.40%	45mg/mL	45mg/mL	45mg/mL	45mg/mL
	PHIX	Glas	BIDI Stick	SBS	iWū	Nord 4	Zumwalt	Renova Zero
<b>Primary constituents</b>								
ISO 20768 puff count	195	191	201	207	448	338	163	163
Intense puff count	89	84	100	128	193	139	87	89
Device mass loss (mg)								
ISO 20768	6.90 ± 0.55	5.72 ± 1.12	4.56 ± 0.21	3.13 ± 0.26	4.10 ± 0.43	11.41 ± 0.37	8.26 ± 0.22	13.17 ± 0.92
Intense	16.28 ± 0.97	13.81 ± 1.95	9.93 ± 0.76	6.80 ± 0.17	10.75 ± 1.39	27.70 ± 2.52	20.77 ± 0.76	23.90 ± 1.43
Nicotine (mg)								
ISO 20768	0.256 ± 0.022	0.250 ± 0.042	0.204 ± 0.030	0.061 ± 0.006	0.144 ± 0.013	0.384 ± 0.021	0.325 ± 0.009	0.407 ± 0.030
Intense	0.559 ± 0.036	0.586 ± 0.072	0.439 ± 0.032	0.115 ± 0.001	0.360 ± 0.048	0.952 ± 0.082	0.704 ± 0.021	0.782 ± 0.098
Propylene glycol (mg)								
ISO 20768	1.66 ± 0.15	2.33 ± 0.46	2.00 ± 0.28	1.89 ± 0.17	0.944 ± 0.085	2.66 ± 0.12	2.04 ± 0.07	2.55 ± 0.25
Intense	3.71 ± 0.28	5.57 ± 0.78	4.17 ± 0.30	3.56 ± 0.04	2.33 ± 0.31	6.49 ± 0.62	4.42 ± 0.18	4.93 ± 0.64
Glycerol (mg)								
ISO 20768	3.53 ± 0.29	1.93 ± 0.36	1.11 ± 0.17	0.92 ± 0.09	2.03 ± 0.31	5.86 ± 0.16	4.52 ± 0.12	6.54 ± 0.39
Intense	7.88 ± 0.47	4.64 ± 0.54	2.39 ± 0.18	1.77 ± 0.04	4.53 ± 0.58	12.88 ± 1.31	10.03 ± 0.26	11.16 ± 1.25

**Table 3. (Continued) Market ENDS HPHCs and chemicals in aerosol – primary constituents (per puff).**

Parameter/constituent	Menthol	Menthol	Menthol	Cool Mint	Menthol	Menthol	Menthol
	2.40%	5.00%	4.80%	5.00%	5.00%	2.40%	1.80%
	MyBlu	ACE	Solo	JUUL	Alto	Alto	Alto
<b>Primary constituents</b>							
ISO 20768 puff count	323	405	149	455	260	272	271
Intense puff count	127	149	111	223	123	126	135
Device mass loss (mg)							
ISO 20768	5.08 ± 0.08	4.55 ± 0.10	2.64 ± 0.14	1.16 ± 0.16	5.64 ± 0.17	6.47 ± 0.43	5.74 ± 0.64
Intense	12.88 ± 0.09	11.16 ± 1.10	3.91 ± 0.13	2.01 ± 0.16	14.30 ± 0.78	13.74 ± 0.41	13.08 ± 1.18
Nicotine (mg)							
ISO 20768	0.101 ± 0.001	0.186 ± 0.002	0.104 ± 0.006	0.054 ± 0.006	0.247 ± 0.005	0.149 ± 0.010	0.091 ± 0.010
Intense	0.252 ± 0.013	0.467 ± 0.068	0.156 ± 0.007	0.09 ± 0.01	0.586 ± 0.061	0.329 ± 0.008	0.210 ± 0.022
Propylene glycol (mg)							
ISO 20768	1.29 ± 0.01	1.30 ± 0.03	0.53 ± 0.03	0.27 ± 0.03	1.74 ± 0.07	2.40 ± 0.18	2.04 ± 0.20
Intense	3.25 ± 0.18	3.14 ± 0.44	0.81 ± 0.03	0.46 ± 0.03	4.25 ± 0.52	5.35 ± 0.20	4.72 ± 0.49
Glycerol (mg)							
ISO 20768	2.89 ± 0.04	1.85 ± 0.04	1.29 ± 0.08	0.67 ± 0.07	2.40 ± 0.05	2.95 ± 0.19	2.50 ± 0.26
Intense	7.23 ± 0.32	4.70 ± 0.62	1.91 ± 0.09	1.10 ± 0.05	5.87 ± 0.55	6.63 ± 0.13	5.72 ± 0.53
Menthol (mg)							
ISO 20768	0.0289 ± 0.0005	0.0096 ± 0.0004	0.011 ± 0.001	0.009 ± 0.001	0.047 ± 0.001	0.052 ± 0.004	0.041 ± 0.005
Intense	0.073 ± 0.003	0.023 ± 0.003	0.014 ± 0.001	0.013 ± 0.001	0.121 ± 0.016	0.137 ± 0.004	0.105 ± 0.017

Parameter/constituent	Mint	Fruit Tea	Tangy Purple	Tobacco Menthol	Menthol	Arctic	Gold	Menthol
	5.00%	3.00%	3.00%	5.00%	5.00%	6.00%	6.00%	2.40%
	RELX	RELX	RELX	PHIX	Glas	BIDI Stick	BIDI Stick	SBS
<b>Primary constituents</b>								
ISO 20768 puff count	294	332	330	192	206	181	213	325
Intense puff count	139	220	177	93	110	87	89	106
Device mass loss (mg)								
ISO 20768	6.48 ± 0.23	5.50 ± 0.31	5.33 ± 0.34	6.62 ± 1.14	5.77 ± 0.45	4.84 ± 0.09	4.70 ± 0.10	2.48 ± 0.12
Intense	12.78 ± 0.85	9.44 ± 0.05	9.19 ± 2.60	15.08 ± 1.21	11.47 ± 0.11	11.09 ± 0.34	11.07 ± 0.46	6.96 ± 0.29
Nicotine (mg)								
ISO 20768	0.277 ± 0.013	0.143 ± 0.008	0.146 ± 0.009	0.253 ± 0.042	0.238 ± 0.023	0.242 ± 0.007	0.266 ± 0.008	0.045 ± 0.003
Intense	0.538 ± 0.045	0.243 ± 0.008	0.252 ± 0.086	0.555 ± 0.063	0.486 ± 0.022	0.564 ± 0.031	0.528 ± 0.019	0.122 ± 0.005
Propylene glycol (mg)								
ISO 20768	0.94 ± 0.05	1.42 ± 0.10	1.75 ± 0.15	1.45 ± 0.25	2.33 ± 0.22	1.67 ± 0.07	2.37 ± 0.07	1.34 ± 0.07
Intense	1.92 ± 0.16	2.57 ± 0.10	3.13 ± 1.09	3.24 ± 0.45	4.80 ± 0.20	3.80 ± 0.23	4.55 ± 0.19	3.66 ± 0.15
Glycerol (mg)								
ISO 20768	3.23 ± 0.13	2.38 ± 0.12	2.10 ± 0.12	3.63 ± 0.62	1.95 ± 0.22	1.55 ± 0.06	1.19 ± 0.06	0.72 ± 0.05
Intense	6.51 ± 0.52	4.08 ± 0.11	3.78 ± 1.03	8.19 ± 0.71	4.01 ± 0.19	3.58 ± 0.24	2.41 ± 0.07	2.07 ± 0.08
Menthol (mg)								
ISO 20768	0.124 ± 0.006	0.043 ± 0.003	0.027 ± 0.002	0.043 ± 0.008	0.026 ± 0.002	0.084 ± 0.003	BLOD (0.0009)	0.027 ± 0.001
Intense	0.275 ± 0.021	0.077 ± 0.003	0.049 ± 0.017	0.089 ± 0.014	0.053 ± 0.002	0.202 ± 0.012	BLOD (0.002)	0.077 ± 0.006

**Table 3. (Continued) Market ENDS HPHCs and chemicals in aerosol – primary constituents (per puff).**

Parameter/constituent	Mr. Salt-E Menthol Ice			
	45 mg/mL	45 mg/mL	45 mg/mL	45 mg/mL
	iWü	Nord 4	Zumwalt	Renova Zero
<b>Primary constituents</b>				
ISO 20768 puff count	369	294	168	142
Intense puff count	126	132	80	77
Device mass loss (mg)				
ISO 20768	5.62 ± 0.31	13.24 ± 0.66	7.91 ± 0.24	14.88 ± 1.07
Intense	15.30 ± 1.59	34.16 ± 2.43	22.94 ± 0.90	28.80 ± 1.43
Nicotine (mg)				
ISO 20768	0.213 ± 0.008	0.517 ± 0.091	0.294 ± 0.008	0.449 ± 0.036
Intense	0.529 ± 0.054	1.109 ± 0.093	0.787 ± 0.064	0.884 ± 0.040
Propylene glycol (mg)				
ISO 20768	1.55 ± 0.06	3.68 ± 0.65	2.05 ± 0.07	3.24 ± 0.41
Intense	3.73 ± 0.37	8.42 ± 0.71	5.53 ± 0.37	6.18 ± 0.28
Glycerol (mg)				
ISO 20768	2.78 ± 0.18	7.18 ± 1.31	4.08 ± 0.09	6.51 ± 0.41
Intense	6.74 ± 0.66	15.31 ± 1.13	10.44 ± 0.61	11.78 ± 0.45
Menthol (mg)				
ISO 20768	0.061 ± 0.003	0.168 ± 0.034	0.087 ± 0.003	0.143 ± 0.016
Intense	0.147 ± 0.014	0.337 ± 0.027	0.192 ± 0.013	0.282 ± 0.009

BLOQ = Below limits of quantitation

BLOD = Below limits of detection

**Table 4. Market ENDS HPHCs and chemicals in aerosol – carbonyls (per puff).**

Parameter/constituent	Rich Tobacco	Classic Tobacco	Tobacco	Golden Tobacco	Rich Tobacco	Rich Tobacco	Rich Tobacco	Classic Tobacco
	2.40%	5.00%	4.80%	5.00%	5.00%	2.40%	1.80%	5.00%
	MyBlu	ACE	Solo	JUUL	Alto	Alto	Alto	RELX
<b>Carbonyls</b>								
ISO 20768 puff count	262	360	156	371	363	339	355	297
Intense puff count	104	213	114	229	140	167	190	140
Device mass loss (mg)								
ISO 20768	5.92 ± 0.44	4.57 ± 0.79	2.21 ± 0.09	1.26 ± 0.12	3.91 ± 0.45	4.27 ± 0.36	4.56 ± 0.45	6.27 ± 0.06
Intense	14.79 ± 1.33	8.63 ± 0.64	3.31 ± 0.10	2.28 ± 0.29	10.81 ± 1.07	9.01 ± 1.55	9.70 ± 1.49	10.52 ± 1.42
Acetaldehyde (µg)								
ISO 20768	2.08 ± 0.97	0.45 ± 0.22	0.065 ± 0.022	0.017 ± 0.008	0.23 ± 0.15	0.38 ± 0.27	0.26 ± 0.09	0.056 ± 0.009
Intense	38.99 ± 22.30	1.11 ± 1.00	0.14 ± 0.04	0.045 ± 0.045	0.42 ± 0.12	1.86 ± 1.07	1.30 ± 0.98	0.49 ± 0.47
Acetyl propionyl (µg)								
ISO 20768	0.010 ± 0.002	0.013 ± 0.005	BLOQ (0.007)	BLOD (0.0003)	0.017 ± 0.012	0.025 ± 0.012	0.019 ± 0.008	BLOQ (0.004)
Intense	0.090 ± 0.039	0.009 ± 0.002	BLOD (0.001)	BLOD (0.0006)	0.021 ± 0.012	0.055 ± 0.022	0.049 ± 0.018	0.017 ± 0.015
Acrolein (µg)								
ISO 20768	0.61 ± 0.26	0.20 ± 0.12	0.022 ± 0.008	0.0092 ± 0.0032	0.14 ± 0.10	0.21 ± 0.10	0.17 ± 0.06	0.035 ± 0.012
Intense	12.25 ± 4.91	0.59 ± 0.68	0.048 ± 0.014	0.026 ± 0.026	0.23 ± 0.10	1.02 ± 0.57	0.21 ± 0.10	0.43 ± 0.36
n-Butyraldehyde (µg)								
ISO 20768	0.009 ± 0.007	BLOQ (0.003)	BLOD (0.0007)	BLOD (0.0003)	0.005 ± 0.001	0.007 ± 0.002	0.006 ± 0.001	BLOQ (0.004)
Intense	0.197 ± 0.112	BLOD (0.0007)	BLOD (0.001)	BLOD (0.0006)	BLOD (0.001)	0.0209 ± 0.005	0.0170 ± 0.004	BLOQ (0.009)
Crotonaldehyde (µg)								
ISO 20768	0.0074 ± 0.0044	BLOQ (0.003)	BLOD (0.001)	BLOD (0.0003)	BLOQ (0.003)	BLOQ (0.003)	BLOQ (0.003)	BLOD (0.0004)
Intense	0.049 ± 0.019	BLOQ (0.006)	BLOD (0.002)	BLOD (0.0006)	BLOD (0.0009)	BLOQ (0.007)	BLOQ (0.008)	BLOQ (0.009)
Diacetyl (µg)								
ISO 20768	0.074 ± 0.013	0.048 ± 0.02	BLOQ (0.007)	BLOQ (0.003)	0.052 ± 0.044	0.086 ± 0.046	0.058 ± 0.028	0.007 ± 0.003
Intense	0.488 ± 0.194	0.034 ± 0.011	BLOQ (0.01)	BLOQ (0.006)	0.076 ± 0.040	0.270 ± 0.101	0.1597 ± 0.067	0.080 ± 0.066
Formaldehyde (µg)								
ISO 20768	4.69 ± 2.60	0.29 ± 0.30	0.081 ± 0.042	0.084 ± 0.042	0.13 ± 0.11	0.40 ± 0.45	0.21 ± 0.15	0.12 ± 0.01
Intense	82.1 ± 40.3	1.56 ± 2.06	0.24 ± 0.10	0.27 ± 0.31	0.26 ± 0.07	3.57 ± 2.39	1.77 ± 2.12	1.12 ± 1.14

BLOQ: Below limits of quantitation, BLOD: Below limits of detection

**Table 4. (Continued) Market ENDS HPHCs and chemicals in aerosol – carbonyls (per puff).**

Parameter/constituent	Original Blend	Signature Tobacco	Classic	Tobacco	Mr. Salt-E Tobacco				
	5.00%	5.00%	6.00%	2.40%	45 mg/mL	45 mg/mL	45 mg/mL	45 mg/mL	
	PHIX	Glas	BIDI Stick	SBS	iWü	Nord 4	Zumwalt	Renova Zero	
<b>Carbonyls</b>									
ISO 20768 puff count	195	191	201	207	448	338	163	163	
Intense puff count	89	84	100	128	193	139	87	89	
Device mass loss (mg)									
ISO 20768	6.54 ± 0.41	5.77 ± 0.74	4.5 ± 0.16	2.99 ± 0.33	4.22 ± 0.48	13.53 ± 0.86	7.82 ± 2.21	11.35 ± 0.53	
Intense	16.76 ± 0.30	13.90 ± 1.08	10.24 ± 0.67	6.58 ± 0.11	11.26 ± 0.39	33.39 ± 2.64	13.12 ± 5.50	25.12 ± 0.82	
Acetaldehyde (µg)									
ISO 20768	0.22 ± 0.06	0.88 ± 1.67	0.035 ± 0.005	1.58 ± 1.86	1.35 ± 1.33	0.44 ± 0.08	18.92 ± 34.26	0.22 ± 0.05	
Intense	4.14 ± 3.91	1.78 ± 3.37	0.13 ± 0.08	15.56 ± 7.32	17.62 ± 13.71	2.04 ± 0.66	6.38 ± 4.98	15.49 ± 1.08	
Acetyl propionyl (µg)									
ISO 20768	BLOQ (0.006)	0.007 ± 0.004	BLOQ (0.006)	BLOQ (0.001)	0.015 ± 0.008	0.009 ± 0.003	0.047 ± 0.044	BLOQ (0.007)	
Intense	0.026 ± 0.005	0.017 ± 0.012	BLOQ (0.01)	0.013 ± 0.002	0.053 ± 0.032	0.039 ± 0.015	0.037 ± 0.026	0.036 ± 0.003	
Acrolein (µg)									
ISO 20768	0.50 ± 0.17	0.32 ± 0.51	0.021 ± 0.006	0.070 ± 0.050	1.20 ± 0.35	0.72 ± 0.11	2.45 ± 2.29	0.17 ± 0.05	
Intense	3.89 ± 2.36	0.66 ± 1.15	0.077 ± 0.050	4.59 ± 1.67	8.76 ± 4.26	2.49 ± 0.68	4.43 ± 1.96	8.44 ± 0.82	
n-Butyraldehyde (µg)									
ISO 20768	BLOD (0.002)	BLOD (0.002)	BLOD (0.001)	BLOD (0.002)	0.025 ± 0.019	0.016 ± 0.001	0.204 ± 0.36	0.0141 ± 0.0003	
Intense	BLOQ(0.01)	BLOD (0.02)	BLOD (0.01)	0.019 ± 0.011	0.197 ± 0.130	0.056 ± 0.014	0.081 ± 0.038	0.207 ± 0.049	
Crotonaldehyde (µg)									
ISO 20768	BLOD (0.001)	BLOQ (0.006)	BLOD (0.001)	BLOD (0.001)	0.015 ± 0.012	BLOQ (0.003)	0.021 ± 0.024	BLOD (0.002)	
Intense	0.017 ± 0.019	BLOQ (0.02)	BLOD (0.01)	0.0145 ± 0.006	0.069 ± 0.026	0.011 ± 0.006	0.084 ± 0.097	0.150 ± 0.017	
Diacetyl (µg)									
ISO 20768	0.015 ± 0.008	0.023 ± 0.017	0.008 ± 0.003	BLOQ (0.001)	0.059 ± 0.019	0.031 ± 0.007	0.157 ± 0.153	BLOQ (0.007)	
Intense	0.085 ± 0.030	0.056 ± 0.053	0.028 ± 0.014	0.103 ± 0.026	0.225 ± 0.120	0.140 ± 0.054	0.160 ± 0.077	0.198 ± 0.021	
Formaldehyde (µg)									
ISO 20768	0.085 ± 0.013	0.93 ± 1.95	0.24 ± 0.03	1.50 ± 1.52	1.54 ± 1.70	0.11 ± 0.03	30.4 ± 50.77	0.066 ± 0.006	
Intense	5.71 ± 6.20	2.31 ± 4.74	0.60 ± 0.11	19.98 ± 10.31	36.34 ± 28.96	0.75 ± 0.48	8.59 ± 9.40	28.44 ± 2.59	

**Table 4. (Continued) Market ENDS HPHCs and chemicals in aerosol – carbonyls (per puff).**

Parameter/constituent	Menthol	Menthol	Menthol	Cool Mint	Menthol	Menthol	Menthol
	2.40%	5.00%	4.80%	5.00%	5.00%	2.40%	1.80%
	MyBlu	ACE	Solo	JUUL	Alto	Alto	Alto
<b>Carbonyls</b>							
ISO 20768 puff count	323	405	149	455	260	272	271
Intense puff count	127	149	111	223	123	126	135
Device mass loss (mg)							
ISO 20768	5.14 ± 0.02	3.98 ± 0.19	2.25 ± 0.10	1.15 ± 0.13	5.5 ± 0.25	6.1 ± 0.32	5.49 ± 0.39
Intense	13.08 ± 0.22	9.56 ± 0.47	3.24 ± 0.09	2.11 ± 0.24	11.69 ± 0.94	12.97 ± 0.60	12.57 ± 0.76
Acetaldehyde (µg)							
ISO 20768	2.05 ± 0.32	0.37 ± 0.09	0.048 ± 0.010	0.013 ± 0.003	0.096 ± 0.016	0.055 ± 0.006	0.062 ± 0.011
Intense	4.56 ± 3.79	1.07 ± 0.70	0.20 ± 0.09	0.023 ± 0.005	0.21 ± 0.03	0.15 ± 0.06	0.17 ± 0.04
Acetyl propionyl (µg)							
ISO 20768	BLOQ (0.004)	0.018 ± 0.008	BLOQ (0.008)	BLOD (0.0004)	0.006 ± 0.002	BLOQ (0.004)	BLOQ (0.004)
Intense	0.010 ± 0.003	0.040 ± 0.033	BLOQ (0.01)	BLOD (0.0006)	BLOQ (0.01)	BLOQ (0.01)	BLOQ (0.01)
Acrolein (µg)							
ISO 20768	1.27 ± 0.14	0.19 ± 0.08	0.022 ± 0.002	0.007 ± 0.001	0.030 ± 0.011	0.022 ± 0.008	0.035 ± 0.018
Intense	3.43 ± 2.71	0.62 ± 0.44	0.084 ± 0.065	0.012 ± 0.004	0.071 ± 0.011	0.084 ± 0.070	0.093 ± 0.026
<i>n</i> -Butyraldehyde (µg)							
ISO 20768	0.014 ± 0.003	BLOQ (0.003)	BLOD (0.0008)	BLOQ (0.002)	BLOQ (0.004)	BLOD (0.0004)	BLOQ (0.004)
Intense	0.022 ± 0.021	BLOD (0.001)	BLOQ (0.01)	BLOQ (0.01)	BLOD (0.001)	BLOQ (0.01)	BLOQ (0.01)
Crotonaldehyde (µg)							
ISO 20768	0.015 ± 0.002	BLOQ (0.003)	BLOD (0.001)	BLOD (0.0002)	BLOD (0.0006)	BLOD (0.0007)	BLOD (0.0007)
Intense	0.029 ± 0.020	BLOQ (0.009)	BLOD (0.002)	BLOD (0.0006)	BLOD (0.001)	BLOD (0.001)	BLOD (0.001)
Diacetyl (µg)							
ISO 20768	0.020 ± 0.003	0.074 ± 0.029	BLOQ (0.008)	BLOQ (0.003)	0.006 ± 0.003	0.006 ± 0.003	0.012 ± 0.005
Intense	0.047 ± 0.024	0.219 ± 0.167	BLOQ (0.01)	BLOQ (0.01)	0.015 ± 0.002	0.018 ± 0.019	0.023 ± 0.008
Formaldehyde (µg)							
ISO 20768	2.72 ± 0.51	0.26 ± 0.06	0.063 ± 0.016	0.054 ± 0.019	0.055 ± 0.019	0.057 ± 0.020	0.057 ± 0.012
Intense	9.34 ± 9.83	1.21 ± 1.03	0.49 ± 0.39	0.11 ± 0.05	0.13 ± 0.05	0.13 ± 0.07	0.22 ± 0.26

**Table 4. (Continued) Market ENDS HPHCs and chemicals in aerosol – carbonyls (per puff).**

Parameter/constituent	Mint	Fruit Tea	Tangy Purple	Tobacco Menthol	Menthol	Arctic	Gold	Menthol
	5.00%	3.00%	3.00%	5.00%	5.00%	6.00%	6.00%	2.40%
	RELX	RELX	RELX	PHIX	Glas	BIDI Stick	BIDI Stick	SBS
<b>Carbonyls</b>								
ISO 20768 puff count	294	332	330	192	206	181	213	325
Intense puff count	139	220	177	93	110	87	89	106
Device mass loss (mg)								
ISO 20768	5.87 ± 0.84	5.00 ± 0.39	4.96 ± 1.22	5.79 ± 0.74	5.57 ± 0.39	4.66 ± 0.19	4.56 ± 0.39	2.45 ± 0.23
Intense	11.98 ± 1.08	8.70 ± 0.95	9.97 ± 1.31	15.81 ± 0.54	11.60 ± 0.15	10.83 ± 0.42	10.37 ± 0.56	6.46 ± 0.28
Acetaldehyde (µg)								
ISO 20768	0.22 ± 0.05	0.062 ± 0.017	0.051 ± 0.006	0.19 ± 0.12	0.60 ± 1.18	0.020 ± 0.007	0.041 ± 0.016	0.62 ± 0.88
Intense	0.72 ± 0.38	1.79 ± 1.47	0.47 ± 0.22	3.27 ± 3.35	6.85 ± 0.91	0.69 ± 0.99	0.088 ± 0.038	4.36 ± 2.19
Acetyl propionyl (µg)								
ISO 20768	BLOQ (0.004)	BLOQ (0.003)	BLOQ (0.003)	BLOQ (0.006)	BLOQ (0.005)	BLOD (0.0006)	BLOQ (0.005)	BLOQ (0.003)
Intense	0.020 ± 0.013	0.010 ± 0.005	BLOQ (0.007)	0.030 ± 0.025	0.030 ± 0.006	BLOQ (0.02)	BLOQ (0.01)	BLOQ (0.01)
Acrolein (µg)								
ISO 20768	0.090 ± 0.052	0.084 ± 0.015	0.081 ± 0.026	0.47 ± 0.33	0.110 ± 0.201	0.022 ± 0.012	0.023 ± 0.010	0.19 ± 0.26
Intense	0.42 ± 0.30	1.47 ± 1.32	0.60 ± 0.09	4.13 ± 3.40	2.19 ± 0.56	0.43 ± 0.50	0.085 ± 0.038	0.58 ± 0.53
n-Butyraldehyde (µg)								
ISO 20768	BLOQ (0.004)	BLOQ (0.003)	BLOQ (0.003)	BLOD (0.002)	BLOD (0.002)	BLOQ (0.006)	BLOD (0.002)	BLOD (0.001)
Intense	BLOQ (0.01)	0.0066 ± 0.004	BLOQ (0.01)	BLOQ (0.01)	BLOQ (0.01)	BLOD (0.002)	BLOD (0.001)	BLOD (0.001)
Crotonaldehyde (µg)								
ISO 20768	BLOD (0.0004)	BLOD (0.0003)	BLOD (0.0003)	BLOD (0.001)	BLOQ (0.005)	BLOD (0.0006)	BLOD (0.0009)	BLOQ (0.003)
Intense	BLOQ (0.01)	BLOQ (0.01)	BLOQ (0.01)	0.017 ± 0.020	0.043 ± 0.004	BLOQ (0.02)	BLOD (0.001)	BLOQ (0.01)
Diacetyl (µg)								
ISO 20768	0.022 ± 0.014	0.007 ± 0.002	0.005 ± 0.001	0.007 ± 0.009	0.013 ± 0.014	BLOQ (0.006)	BLOQ (0.005)	0.005 ± 0.003
Intense	0.098 ± 0.062	0.074 ± 0.036	0.034 ± 0.010	0.122 ± 0.110	0.135 ± 0.054	0.044 ± 0.029	BLOQ (0.02)	0.030 ± 0.042
Formaldehyde (µg)								
ISO 20768	0.32 ± 0.10	0.10 ± 0.03	0.061 ± 0.007	0.094 ± 0.052	0.76 ± 1.59	0.10 ± 0.02	0.15 ± 0.13	1.12 ± 1.69
Intense	1.32 ± 1.22	8.63 ± 12.34	1.15 ± 0.68	4.73 ± 5.37	9.34 ± 2.67	1.38 ± 1.79	0.35 ± 0.21	4.69 ± 2.63

**Table 4. (Continued) Market ENDS HPHCs and chemicals in aerosol – carbonyls (per puff).**

Parameter/constituent	Mr. Salt-E Menthol Ice			
	45mg/mL	45mg/mL	45mg/mL	45mg/mL
	iWü	Nord 4	Zumwalt	Renova Zero
<b>Carbonyls</b>				
ISO 20768 puff count	369	294	168	142
Intense puff count	126	132	80	77
Device mass loss (mg)				
ISO 20768	5.38 ± 0.26	13.68 ± 1.06	8.96 ± 1.25	9.9 ± 1.64
Intense	16.54 ± 0.54	37.28 ± 2.30	12.09 ± 5.61	25.36 ± 4.38
Acetaldehyde (µg)				
ISO 20768	1.79 ± 1.33	0.10 ± 0.02	2.99 ± 3.26	0.12 ± 0.04
Intense	2.06 ± 1.74	0.75 ± 0.26	6.82 ± 3.88	14.16 ± 11.69
Acetyl propionyl (µg)				
ISO 20768	0.007 ± 0.004	BLOD (0.0005)	0.011 ± 0.020	BLOQ (0.008)
Intense	BLOQ (0.01)	0.010 ± 0.005	BLOQ (0.02)	BLOQ (0.02)
Acrolein (µg)				
ISO 20768	1.68 ± 1.22	0.17 ± 0.08	2.60 ± 2.85	0.048 ± 0.026
Intense	2.55 ± 1.00	1.57 ± 0.57	5.34 ± 3.85	7.53 ± 6.01
n-Butyraldehyde (µg)				
ISO 20768	0.055 ± 0.007	BLOD (0.001)	0.032 ± 0.040	BLOD (0.001)
Intense	BLOQ (0.01)	BLOQ (0.01)	0.064 ± 0.039	0.120 ± 0.105
Crotonaldehyde (µg)				
ISO 20768	0.012 ± 0.013	BLOD (0.001)	0.021 ± 0.025	BLOD (0.001)
Intense	0.014 ± 0.019	BLOQ (0.01)	0.085 ± 0.051	0.095 ± 0.069
Diacetyl (µg)				
ISO 20768	0.031 ± 0.019	BLOQ (0.004)	0.047 ± 0.071	BLOQ (0.008)
Intense	0.051 ± 0.030	0.052 ± 0.035	0.084 ± 0.044	0.061 ± 0.041
Formaldehyde (µg)				
ISO 20768	3.65 ± 2.57	0.079 ± 0.014	4.19 ± 5.02	0.11 ± 0.07
Intense	2.84 ± 3.05	1.17 ± 1.41	9.27 ± 5.49	21.57 ± 17.82

**Table 5. Market ENDS HPHCs and chemicals in aerosol – metals (per puff).**

Parameter/constituent	Rich Tobacco	Classic Tobacco	Tobacco	Golden Tobacco	Rich Tobacco	Rich Tobacco	Rich Tobacco	Classic Tobacco
	2.40%	5.00%	4.80%	5.00%	5.00%	2.40%	1.80%	5.00%
	MyBlu	ACE	Solo	JUUL	Alto	Alto	Alto	RELX
<b>Metals</b>								
ISO 20768 puff count	262	360	156	371	363	339	355	297
Intense puff count	104	213	114	229	140	167	190	140
Device mass loss (mg)								
ISO 20768	6.07 ± 0.27	5.11 ± 0.14	2.53 ± 0.05	1.06 ± 0.19	4.23 ± 0.47	5.13 ± 0.40	4.93 ± 0.43	6.16 ± 1.37
Intense	14.55 ± 0.71	8.92 ± 0.45	3.25 ± 0.07	2.17 ± 0.64	10.81 ± 1.11	9.02 ± 1.62	10.28 ± 0.78	12.06 ± 2.30
Chromium (ng)								
ISO 20768	1.47 ± 1.14	0.59 ± 0.10	BLOD (0.06)	BLOD (0.03)	BLOQ (0.1)	BLOQ (0.1)	BLOQ (0.1)	BLOQ (0.2)
Intense	2.92 ± 3.64	0.72 ± 0.27	BLOD (0.09)	BLOQ (0.2)	BLOQ (0.4)	BLOQ (0.3)	BLOD (0.06)	BLOD (0.07)
Copper (ng)								
ISO 20768	BLOD (0.1)	1.93 ± 0.8	BLOQ (0.5)	BLOD (0.1)	1.81 ± 1.39	2.77 ± 3.71	BLOQ (0.2)	0.77 ± 0.48
Intense	BLOD (0.27)	3.85 ± 0.61	BLOQ (0.7)	BLOQ (0.3)	5.96 ± 9.27	10.88 ± 15.46	BLOQ(0.81)	0.77 ± 0.71
Iron (ng)								
ISO 20768	2.46 ± 0.87	1.43 ± 0.21	BLOD (0.6)	BLOD (0.3)	BLOD (0.3)	BLOD (0.3)	BLOD (0.3)	BLOQ (0.7)
Intense	8.34 ± 3.45	1.25 ± 1.02	BLOD (1.8)	BLOQ (0.9)	BLOD (0.7)	BLOQ (1.1)	BLOD (0.6)	BLOD (0.7)
Lead (ng)								
ISO 20768	BLOQ (0.04)	2.77 ± 1.00	BLOD (0.02)	BLOD (0.01)	1.38 ± 1.35	BLOQ (0.03)	BLOD (0.01)	BLOQ (0.03)
Intense	BLOD (0.02)	8.99 ± 4.97	BLOD (0.02)	BLOQ (0.04)	BLOD (0.02)	BLOD (0.01)	BLOD (0.01)	BLOD (0.02)
Nickel (ng)								
ISO 20768	1.1 ± 0.42	12.13 ± 2.71	0.084 ± 0.089	BLOD (0.01)	1.51 ± 0.88	0.47 ± 0.2	0.20 ± 0.05	1.11 ± 0.78
Intense	3.20 ± 1.62	12.17 ± 6.57	BLOD (0.04)	0.12 ± 0.23	2.05 ± 1.76	1.05 ± 0.42	0.40 ± 0.15	1.03 ± 0.72
Zinc (ng)								
ISO 20768	BLOD (0.6)	25.87 ± 5.93	BLOD (1.0)	BLOD (0.4)	15.91 ± 15.57	7.26 ± 5.71	1.42 ± 1.32	11.7 ± 8.5
Intense	BLOD (1.4)	48.55 ± 15.47	BLOQ (3.1)	BLOQ (1.6)	8.75 ± 5.54	17.38 ± 14.66	BLOQ (2.1)	8.55 ± 3.54

BLOQ: Below limits of quantitation, BLOD: Below limits of detection

**Table 5. (Continued) Market ENDS HPHCs and chemicals in aerosol – metals (per puff).**

Parameter/constituent	Original Blend	Signature Tobacco	Classic	Tobacco	Mr. Salt-E Tobacco				
	5.00%	5.00%	6.00%	2.40%	45 mg/mL	45 mg/mL	45 mg/mL	45 mg/mL	
	PHIX	Glas	BIDI Stick	SBS	iWÜ	Nord 4	Zumwalt	Renova Zero	
<b>Metals</b>									
ISO 20768 puff count	195	191	201	207	448	338	163	163	
Intense puff count	89	84	100	128	193	139	87	89	
Device mass loss (mg)									
ISO 20768	6.42 ± 0.57	6.22 ± 0.37	4.80 ± 0.15	3.49 ± 0.20	3.66 ± 0.22	12.60 ± 1.20	8.62 ± 0.54	11.44 ± 0.81	
Intense	14.15 ± 1.04	15.01 ± 0.80	10.41 ± 0.40	6.55 ± 0.21	11.16 ± 0.75	31.10 ± 4.25	16.89 ± 2.73	25.55 ± 2.08	
Chromium (ng)									
ISO 20768	BLOD (0.05)	1.04 ± 1.07	BLOQ (0.2)	BLOD (0.05)	BLOQ (0.1)	BLOQ (0.1)	1.13 ± 0.34	1.30 ± 1.15	
Intense	BLOD (0.1)	1.48 ± 0.58	BLOQ (0.5)	BLOD (0.08)	0.61 ± 1.30	0.72 ± 1.43	2.70 ± 1.70	3.01 ± 3.70	
Copper (ng)									
ISO 20768	BLOQ (0.4)	17.74 ± 16.55	BLOD (0.1)	BLOQ (0.4)	BLOD (0.1)	0.86 ± 0.91	BLOD (0.2)	BLOQ (0.5)	
Intense	BLOQ (0.8)	28.34 ± 20.67	BLOD (0.3)	0.67 ± 0.60	BLOQ (0.4)	1.53 ± 2.20	BLOQ (0.9)	3.54 ± 3.13	
Iron (ng)									
ISO 20768	BLOD (0.5)	7.81 ± 5.67	BLOD (0.5)	BLOD (0.5)	BLOD (0.2)	1.09 ± 0.35	5.00 ± 1.50	3.71 ± 1.87	
Intense	BLOD (1.1)	13.59 ± 4.11	BLOQ (2.0)	BLOQ (1.6)	BLOD (0.5)	3.52 ± 6.67	7.61 ± 5.30	9.76 ± 15.27	
Lead (ng)									
ISO 20768	BLOQ (0.05)	4.22 ± 4.04	BLOQ (0.05)	BLOQ (0.05)	BLOQ (0.02)	0.48 ± 0.42	0.11 ± 0.06	BLOQ (0.06)	
Intense	BLOQ (0.1)	6.72 ± 5.20	BLOQ (0.1)	0.082 ± 0.120	1.24 ± 1.72	1.35 ± 2.40	0.19 ± 0.12	3.62 ± 4.60	
Nickel (ng)									
ISO 20768	BLOQ (0.05)	30.85 ± 16.91	0.86 ± 0.2	0.12 ± 0.05	0.68 ± 0.40	5.47 ± 4.56	17.92 ± 9.57	0.62 ± 0.67	
Intense	0.23 ± 0.17	60.97 ± 23.36	1.50 ± 0.64	0.32 ± 0.34	4.41 ± 2.67	17.63 ± 25.85	26.65 ± 17.42	21.91 ± 24.42	
Zinc (ng)									
ISO 20768	BLOQ (1.8)	29.87 ± 32.44	BLOQ (1.7)	BLOQ (1.7)	BLOD (0.3)	2.75 ± 2.42	2.49 ± 1.32	BLOD (0.9)	
Intense	BLOQ (3.9)	51.33 ± 49.12	4.60 ± 3.69	BLOQ (2.7)	10.25 ± 18.42	7.80 ± 10.14	9.60 ± 10.52	10.65 ± 10.48	

**Table 5. (Continued) Market ENDS HPHCs and chemicals in aerosol – metals (per puff).**

Parameter/constituent	Menthol	Menthol	Menthol	Cool Mint	Menthol	Menthol	Menthol
	2.40%	5.00%	4.80%	5.00%	5.00%	2.40%	1.80%
	MyBlu	ACE	Solo	JUUL	Alto	Alto	Alto
<b>Metals</b>							
ISO 20768 puff count	323	405	149	455	260	272	271
Intense puff count	127	149	111	223	123	126	135
Device mass loss (mg)							
ISO 20768	4.98 ± 0.07	4.31 ± 0.35	2.60 ± 0.07	1.15 ± 0.16	6.26 ± 0.12	6.59 ± 0.24	6.66 ± 0.29
Intense	12.64 ± 0.34	9.91 ± 1.05	3.31 ± 0.15	2.01 ± 0.46	13.61 ± 0.96	13.77 ± 0.72	13.95 ± 0.33
Chromium (ng)							
ISO 20768	0.24 ± 0.28	0.29 ± 0.19	BLOD (0.07)	BLOD (0.02)	0.45 ± 0.04	0.33 ± 0.04	BLOQ (0.2)
Intense	1.12 ± 1.29	0.72 ± 0.69	BLOD (0.09)	BLOD (0.04)	0.60 ± 0.09	0.64 ± 0.16	BLOQ (0.4)
Copper (ng)							
ISO 20768	BLOQ (0.2)	2.45 ± 1.52	BLOQ (0.5)	BLOD (0.1)	1.44 ± 0.70	1.11 ± 1.12	0.94 ± 0.58
Intense	BLOD (0.2)	7.30 ± 2.60	BLOD (0.2)	BLOQ (0.3)	12.83 ± 8.87	12.22 ± 11.34	15.17 ± 5.77
Iron (ng)							
ISO 20768	BLOQ (0.6)	0.76 ± 0.41	BLOD (0.7)	BLOD (0.2)	0.95 ± 0.13	0.99 ± 0.11	0.83 ± 0.27
Intense	BLOQ (1.6)	2.30 ± 1.14	BLOD (1.8)	BLOQ (0.9)	2.07 ± 0.51	2.16 ± 0.28	BLOQ (1.5)
Lead (ng)							
ISO 20768	0.15 ± 0.24	BLOQ (0.02)	BLOD (0.02)	BLOD (0.01)	0.20 ± 0.43	BLOQ (0.04)	BLOQ (0.04)
Intense	BLOD (0.02)	BLOQ (0.07)	BLOD (0.02)	BLOD (0.01)	BLOQ (0.08)	BLOD (0.02)	BLOD (0.02)
Nickel (ng)							
ISO 20768	BLOQ (0.03)	3.57 ± 1.92	BLOQ (0.07)	BLOD (0.01)	5.23 ± 0.61	3.56 ± 0.55	2.42 ± 0.63
Intense	BLOQ (0.1)	9.56 ± 5.64	BLOQ (0.1)	BLOD (0.04)	7.77 ± 1.73	6.80 ± 1.37	2.65 ± 1.33
Zinc (ng)							
ISO 20768	BLOQ (1.1)	48.55 ± 21.93	BLOQ (2.3)	BLOD (0.3)	6.90 ± 2.29	4.13 ± 1.42	12.69 ± 10.37
Intense	BLOQ (2.8)	126.11 ± 39.58	BLOQ (3.2)	BLOD (0.7)	46.12 ± 28.96	25.10 ± 18.44	24.03 ± 9.66

**Table 5. (Continued) Market ENDS HPHCs and chemicals in aerosol – metals (per puff).**

Parameter/constituent	Mint	Fruit Tea	Tangy Purple	Tobacco Menthol	Menthol	Arctic	Gold	Menthol	
	5.00%	3.00%	3.00%	5.00%	5.00%	6.00%	6.00%	2.40%	
	RELX	RELX	RELX	PHIX	Glas	BIDI Stick	BIDI Stick	SBS	
<b>Metals</b>									
ISO 20768 puff count	294	332	330	192	206	181	213	325	
Intense puff count	139	220	177	93	110	87	89	106	
Device mass loss (mg)									
ISO 20768	5.82 ± 0.76	4.72 ± 1.24	5.90 ± 0.24	6.05 ± 1.09	5.65 ± 0.86	4.88 ± 0.31	4.94 ± 0.05	2.54 ± 0.06	
Intense	11.76 ± 1.71	8.29 ± 1.09	7.30 ± 2.65	15.47 ± 1.57	11.65 ± 0.11	11.37 ± 0.28	11.14 ± 0.25	6.65 ± 0.50	
Chromium (ng)									
ISO 20768	BLOQ (0.2)	BLOQ (0.2)	0.25 ± 0.09	BLOD (0.05)	0.32 ± 0.24	BLOD (0.06)	BLOQ (0.2)	BLOD (0.03)	
Intense	BLOD (0.07)	BLOQ (0.2)	BLOQ (0.3)	BLOD (0.1)	0.55 ± 0.23	BLOQ (0.6)	BLOQ (0.6)	BLOD (0.09)	
Copper (ng)									
ISO 20768	BLOQ (0.3)	3.25 ± 2.68	22.58 ± 7.68	BLOD (0.1)	4.41 ± 3.26	BLOD (0.1)	BLOQ (0.4)	BLOD (0.1)	
Intense	0.64 ± 0.52	13.57 ± 5.74	11.79 ± 13.99	BLOQ (0.8)	23.86 ± 11.26	BLOD (0.3)	BLOD (0.3)	BLOD (0.2)	
Iron (ng)									
ISO 20768	BLOQ (0.7)	BLOQ (0.6)	1.51 ± 0.37	BLOD (0.5)	3.45 ± 2.37	BLOD (0.6)	BLOD (0.5)	BLOD (0.3)	
Intense	BLOQ (1.4)	BLOQ (0.9)	1.29 ± 0.82	BLOD (1.1)	4.93 ± 1.98	BLOD (1.1)	BLOD (1.1)	BLOD (0.9)	
Lead (ng)									
ISO 20768	BLOD (0.01)	BLOD (0.01)	BLOQ (0.03)	BLOD (0.01)	0.49 ± 0.54	0.08 ± 0.11	0.17 ± 0.32	BLOD (0.01)	
Intense	BLOQ (0.07)	BLOQ (0.05)	BLOQ (0.06)	0.18 ± 0.17	4.34 ± 1.98	BLOQ (0.1)	BLOQ (0.1)	BLOD (0.02)	
Nickel (ng)									
ISO 20768	0.72 ± 0.35	0.41 ± 0.20	4.77 ± 1.76	BLOQ (0.05)	6.03 ± 3.65	0.61 ± 0.34	2.24 ± 1.89	BLOQ (0.02)	
Intense	1.37 ± 0.80	1.51 ± 0.87	2.56 ± 3.21	0.15 ± 0.07	17.20 ± 8.05	1.41 ± 0.58	4.79 ± 1.50	BLOQ (0.09)	
Zinc (ng)									
ISO 20768	15.84 ± 5.67	4.28 ± 2.7	27.43 ± 8.62	BLOQ (1.8)	4.48 ± 3.38	4.93 ± 1.38	2.09 ± 1.27	BLOD (0.5)	
Intense	31.96 ± 24.98	18.96 ± 6.87	19.58 ± 12.01	7.74 ± 4.77	27.32 ± 20.51	21.55 ± 13.81	BLOQ (3.9)	BLOD (1.4)	

**Table 5. (Continued) Market ENDS HPHCs and chemicals in aerosol – metals (per puff).**

Parameter/constituent	Mr. Salt-E Menthol Ice			
	45 mg/mL	45 mg/mL	45 mg/mL	45 mg/mL
	iWü	Nord 4	Zumwalt	Renova Zero
<b>Metals</b>				
ISO 20768 puff count	369	294	168	142
Intense puff count	126	132	80	77
Device mass loss (mg)				
ISO 20768	4.73 ± 0.63	12.12 ± 1.16	7.96 ± 0.36	13.53 ± 0.96
Intense	16.44 ± 1.20	30.55 ± 2.80	19.10 ± 0.64	27.32 ± 2.74
Chromium (ng)				
ISO 20768	BLOQ (0.1)	0.24 ± 0.17	0.36 ± 0.19	0.45 ± 0.21
Intense	BLOQ (0.4)	BLOQ (0.4)	BLOQ (0.6)	0.96 ± 1.07
Copper (ng)				
ISO 20768	BLOQ (0.2)	1.59 ± 1.22	BLOQ (0.4)	BLOQ (0.5)
Intense	3.93 ± 5.45	8.69 ± 13.06	BLOQ (0.9)	8.50 ± 5.74
Iron (ng)				
ISO 20768	BLOD (0.3)	2.22 ± 1.08	1.91 ± 0.80	2.06 ± 0.60
Intense	BLOD (1.6)	BLOQ (1.5)	4.06 ± 0.31	5.80 ± 4.47
Lead (ng)				
ISO 20768	0.16 ± 0.27	2.48 ± 4.23	0.24 ± 0.15	0.10 ± 0.07
Intense	1.82 ± 2.27	2.74 ± 3.67	1.37 ± 0.68	3.44 ± 3.76
Nickel (ng)				
ISO 20768	0.99 ± 0.79	16.31 ± 12.82	10.36 ± 2.3	0.82 ± 0.45
Intense	48.30 ± 62.10	19.63 ± 8.72	39.97 ± 18.76	25.96 ± 13.56
Zinc (ng)				
ISO 20768	BLOQ (0.9)	24.02 ± 47.94	2.34 ± 0.51	BLOD (1.1)
Intense	5.94 ± 6.67	49.40 ± 97.50	7.51 ± 2.43	19.85 ± 22.56

**Table 6. Market ENDS HPHCs and chemicals in aerosol – glycidol (per puff).**

Parameter/constituent	Rich Tobacco	Classic Tobacco	Tobacco	Golden Tobacco	Rich Tobacco	Rich Tobacco	Rich Tobacco	Classic Tobacco
	2.40%	5.00%	4.80%	5.00%	5.00%	2.40%	1.80%	5.00%
	MyBlu	ACE	Solo	JUUL	Alto	Alto	Alto	RELX
<b>Glycidol</b>								
ISO 20768 puff count	284	289	156	371	314	339	355	300
Intense puff count	103	134	114	223	150	190	167	155
Device mass loss (mg)								
ISO 20768	5.01 ± 0.32	6.18 ± 0.27	2.43 ± 0.10	1.18 ± 0.23	4.37 ± 0.71	4.29 ± 0.82	4.34 ± 0.86	5.97 ± 0.48
Intense	11.53 ± 1.90	9.39 ± 0.29	3.81 ± 0.20	2.45 ± 0.27	10.55 ± 0.60	9.51 ± 1.50	8.15 ± 0.74	10.30 ± 2.11
Glycidol (µg)								
ISO 20768	0.16 ± 0.1	0.10 ± 0.03	0.030 ± 0.014	0.006 ± 0.002	0.38 ± 0.08	0.36 ± 0.08	0.45 ± 0.09	0.047 ± 0.012
Intense	0.56 ± 0.31	0.16 ± 0.04	0.030 ± 0.008	0.004 ± 0.001	1.33 ± 0.31	1.19 ± 0.40	1.19 ± 0.21	0.30 ± 0.07

Parameter/constituent	Original Blend	Signature Tobacco	Classic	Tobacco	Mr. Salt-E Tobacco			
	5.00%	5.00%	6.00%	2.40%	45 mg/mL	45 mg/mL	45 mg/mL	45 mg/mL
	PHIX	Glas	BIDI Stick	SBS	iWü	Nord 4	Zumwalt	Renova Zero
<b>Glycidol</b>								
ISO 20768 puff count	191	179	201	207	448	338	163	163
Intense puff count	91	77	100	128	193	139	87	89
Device mass loss (mg)								
ISO 20768	6.58 ± 0.74	4.6 ± 1.54	4.09 ± 0.32	3.04 ± 0.55	3.87 ± 0.49	4.07 ± 0.86	8.26 ± 0.58	11.56 ± 0.86
Intense	15.23 ± 0.64	13.75 ± 0.33	9.92 ± 0.33	6.20 ± 0.26	9.15 ± 1.96	35.66 ± 2.54	13.76 ± 4.28	19.54 ± 3.25
Glycidol (µg)								
ISO 20768	0.13 ± 0.03	0.29 ± 0.25	0.030 ± 0.038	0.021 ± 0.01	0.13 ± 0.11	0.74 ± 0.59	0.030 ± 0.031	0.019 ± 0.018
Intense	0.48 ± 0.16	0.74 ± 0.32	0.018 ± 0.007	0.11 ± 0.09	1.10 ± 0.57	0.46 ± 0.25	0.46 ± 0.54	0.74 ± 1.05

Parameter/constituent	Menthol	Menthol	Menthol	Cool Mint	Menthol	Menthol	Menthol
	2.40%	5.00%	4.80%	5.00%	5.00%	2.40%	1.80%
	MyBlu	ACE	Solo	JUUL	Alto	Alto	Alto
<b>Glycidol</b>							
ISO 20768 puff count	263	292	149	455	262	272	271
Intense puff count	100	139	111	229	124	126	135
Device mass loss (mg)							
ISO 20768	4.45 ± 0.21	4.47 ± 0.13	2.51 ± 0.08	1.22 ± 0.13	4.75 ± 1.00	6.16 ± 0.43	6.70 ± 0.27
Intense	12.03 ± 0.38	9.86 ± 1.31	3.28 ± 0.06	2.03 ± 0.33	11.37 ± 1.14	13.81 ± 0.52	13.27 ± 1.10
Glycidol (µg)							
ISO 20768	0.099 ± 0.012	0.061 ± 0.015	0.036 ± 0.008	0.0060 ± 0.0005	0.18 ± 0.13	0.072 ± 0.026	0.10 ± 0.02
Intense	0.22 ± 0.03	0.11 ± 0.03	0.19 ± 0.06	0.0050 ± 0.0004	0.23 ± 0.09	0.19 ± 0.04	0.38 ± 0.27

**Table 6. (Continued) Market ENDS HPHCs and chemicals in aerosol – glycidol (per puff).**

Parameter/constituent	Mint	Fruit Tea	Tangy Purple	Tobacco Menthol	Menthol	Arctic	Gold	Menthol
	5.00%	3.00%	3.00%	5.00%	5.00%	6.00%	6.00%	2.40%
	RELX	RELX	RELX	PHIX	Glas	BIDI Stick	BIDI Stick	SBS
<b>Glycidol</b>								
ISO 20768 puff count	294	332	287	200	162	181	213	325
Intense puff count	139	220	140	89	79	87	89	106
Device mass loss (mg)								
ISO 20768	5.04 ± 0.59	4.47 ± 0.82	4.51 ± 0.67	5.84 ± 0.55	4.56 ± 0.4	4.41 ± 0.11	4.49 ± 0.18	2.47 ± 0.10
Intense	11.47 ± 0.44	7.90 ± 0.93	7.42 ± 3.00	14.65 ± 0.61	10.75 ± 0.12	10.72 ± 0.24	10.10 ± 1.28	6.16 ± 0.34
Glycidol (µg)								
ISO 20768	0.047 ± 0.012	0.025 ± 0.022	0.16 ± 0.03	0.23 ± 0.02	0.090 ± 0.037	0.015 ± 0.008	0.006 ± 0.002	0.026 ± 0.008
Intense	0.015 ± 0.002	0.020 ± 0.011	0.41 ± 0.15	0.68 ± 0.13	0.55 ± 0.24	0.046 ± 0.023	0.053 ± 0.027	0.072 ± 0.029

Parameter/constituent	Mr. Salt-E Menthol Ice			
	45 mg/mL	45 mg/mL	45 mg/mL	45 mg/mL
	iWü	Nord 4	Zumwalt	Renova Zero
<b>Glycidol</b>				
ISO 20768 puff count	369	294	168	142
Intense puff count	126	132	80	77
Device mass loss (mg)				
ISO 20768	5.37 ± 0.1	8.11 ± 4.73	8.02 ± 0.38	10.76 ± 1.88
Intense	9.89 ± 1.57	38.29 ± 2.04	18.09 ± 0.50	23.98 ± 0.79
Glycidol (µg)				
ISO 20768	0.003 ± 0.001	0.47 ± 0.31	0.003 ± 0.001	0.004 ± 0.002
Intense	0.24 ± 0.16	0.088 ± 0.022	0.063 ± 0.051	0.011 ± 0.010