Fuel Supply Defaults

Regional Fuels and the Fuel Wizard in MOVES5

United States Environmental Protection Agency

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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1. Introduction

The United States Environmental Protection Agency's Motor Vehicle Emission Simulator—commonly referred to as MOVES—is a set of modeling tools for estimating air pollution emissions produced by onroad (highway) and nonroad mobile sources. MOVES estimates the emissions of greenhouse gases (GHGs), criteria pollutants and selected air toxics. The MOVES model is currently the official model for use for state implementation plan (SIP) submissions to EPA and for transportation conformity analyses outside of California. The model is also the primary modeling tool for estimating the impact of mobile source regulations on emission inventories. This document describes the fuel supply components of MOVES and methodology used to develop them. Fuel-related emission adjustments are described in a separate document.[14]

MOVES estimates emissions of onroad vehicles and nonroad equipment using the "fuel types" gasoline (E0 through E15), diesel (including biodiesel blends), compressed natural gas (CNG), E85 ethanol blends, and electricity. MOVES also models nonroad equipment using liquified petroleum gas (LPG), and onroad vehicles powered by batteries or fuel cells using the electricity fuel type.[a] MOVES does not currently model use of liquified natural gas (LNG) due to its small market share and lack of related data. MOVES also does not currently model emission impacts of renewable diesel, and thus it is not necessary to account for it in the fuel supply. Within the gasoline and diesel fuel types, the model considers different fuel subtypes, as shown in Table 1-1. Each of these subtypes has a number of specific formulations that vary with region, season, and calendar year. More information on nonroad fuels is available in Section 6.

The MOVES fuel supply is primarily comprised of three tables that reference each other. The regionCounty table assigns a fuel region to each county for each calendar year (CY). This allows a given county to change fuel regions over time, which may occur if a local area adopts a volatility control program, for example. The fuelSupply table designates fuelFormulationIDs and marketShares for each fuel region by month and year, which allows formulations to change by season as well as over the years as federal regulations or other blending practices change. The fuelFormulation table assigns specific properties, such as ethanol, aromatics, and sulfur level, to each fuelFormulationID. Two other tables, fuelType and fuelSubtype, specify additional properties like density, carbon, and energy content, that are applied to emission computations that don't vary with individual formulations. An additional table (fuelUsageFactor) sets the fraction of Flex-Fuel Vehicle fuel usage that is E85 versus gasoline.

The default fuel supply in MOVES5 uses the same regional fuel structure as in MOVES4. Significant updates were made for 2021 and later gasoline fuel formulations to make use of a large number of retail fuel samples now available to EPA following the 2020 fuels regulatory streamlining rule.[b] This survey is described in more detail later in this document.

[a] While hydrogen may be used in fuel cells, it is not considered a fuel type in MOVES and the model does not quantify any emissions from its combustion, refueling, or leakage.
[b] See 85 Fed. Reg 78412.

Table 1-1. Fuel subtypes in MOVES.

TypeID	SubtypeID	Description	Application Type
1	10	Conventional Gasoline (CG)	Onroad + Nonroad
1	11	Reformulated Gasoline (RFG)	Onroad + Nonroad
1	12	Gasohol (E10)	Onroad + Nonroad
1	13	Gasohol (E8)	Onroad + Nonroad
1	14	Gasohol (E5)	Onroad + Nonroad
1	15	Gasohol (E15)	Onroad
2	20	Conventional Diesel Fuel	Onroad + Nonroad
2	21	Biodiesel Blend	Onroad + Nonroad
2	23	Nonroad Diesel Fuel	Nonroad
2	24	Marine Diesel Fuel	Nonroad
3	30	Compressed Natural Gas (CNG)	Onroad
4	40	Liquefied Petroleum Gas (LPG)	Nonroad
5	51	Ethanol (E85)[a]	Onroad
9	90	Electricity	Onroad

[a] Subtype 51 currently uses a single blend level of 74% ethanol to represent a national annual average, with two RVP levels (summer and winter).

The document is organized into the following sections plus three appendices.

- Sections 2 and 3 describe development of the geographical areas used in the fuel supply.
- Section 4 describes development of the gasoline fuel formulations.
- Sections 5 describes the onroad diesel, CNG and E85 fuel characteristics.
- Section 6 describe the fuel supply used for nonroad equipment.
- Section 7 describes the Fuel Wizard tool used to estimate secondary fuel property changes for gasoline blending.
- Appendix A provides color-coded maps showing which counties correspond with which regionIDs for years 1990-2024.
- Appendix B presents average gasoline formulation trends over years 2000-2024.
- Appendix C presents a comparison between the MOVES5 and MOVES4 fuel formulations for 2021 and later.

The fuel supply documentation has undergone three peer-reviews since the release of MOVES2014, pursuant to EPA's peer review guidance.[1] In 2017, we peer-reviewed an internal version referred to as "MOVES201X" that included updates to MOVES2014.[2] In 2020, we conducted another peer-review of further updates for MOVES3.[3] The most recent peer review was conducted in 2024 on a draft version of MOVES5. Improvements to the fuel supply were made in response to peer-review comments in all cases. Materials from each peer review, including peer-review comments and EPA responses are located on the EPA's science inventory webpage.[c]

[c] https://cfpub.epa.gov/si/

2. Development of Base Fuel Regions

The base fuel regions in MOVES were developed starting from Petroleum Area for Defense District boundaries (a historic division of fuel supply areas developed in the 1950s) along with locations of fuel terminals and pipelines using data from Oil Price Information Service (OPIS) and Energy Information Administration (EIA), which allowed grouping of areas sharing connections to similar refined product delivery networks.[4,5] A dividing line between base regions 1 and 2 can be seen along the Appalachians, with major pipelines forming a distribution corridor running from Houston, Texas, to the east side of the mountain range and up into New England. Meanwhile, another product network runs north from the Houston area into the midwest and plains states that comprise base regions 2 and 3. A high-level depiction of these pipelines overlaid onto state boundaries is shown in Figure 2-1. This analysis, along with reformulated gasoline requirements in some areas, led to the base fuel regions described in Table 2-1 and shown in Figure 3-1.

Figure 2-1. Illustration of petroleum product pipelines in the continental United States[5]

Table 2-1. Base fuel region ID numbers and general descriptions.

Region ID	Base Region Name	General Description
1	**East Coast, Caribbean**	East coast states, west to Appalachians; Florida and Gulf Coast region; Puerto Rico and U.S. Virgin Islands
2	**Midwest**	Midwest states, east to Appalachians; Tennessee; Kentucky
3	**South**	Iowa to Texas (North to South); Alabama to New Mexico (East to West); does not include counties along the Gulf Coast
4	**North**	North and South Dakota, Minnesota, Wisconsin
5	**Rocky Mtns.**	Pacific Northwest, Rocky Mountain states
6	**AZ/NV/HI**	Arizona except Phoenix area; Nevada; Hawaii
7	**Alaska**	All Alaska counties
11	**East Coast RFG**	East coast states and regions using reformulated gasoline (RFG)
12	**MD/VA RFG**	Maryland and Virginia regions using RFG
13	**Texas RFG**	Texas regions using RFG
14	**Midwest RFG**	Midwest regions using RFG
15	**California RFG**	California and Phoenix-area counties using fuel produced by California refineries
16	**Colorado RFG**	Denver-area counties using RFG

3. Incorporation of Local Gasoline Programs

After developing the base fuel regions, areas of local gasoline controls were added. Such controls exist in areas where local authorities have attempted to improve air quality by changing the gasoline formulation requirements (e.g., lower limits on RVP or sulfur). The regionCounty table assigns a region [*regionID*] to each county [*countyID*] in a given year [*fuelYearID*], including regions with state or local fuel control programs. Each county also has an identifier [*regionCodeID*] which allows separate fuel regions for onroad and nonroad gasoline applications (though this is not exercised in the default supply).

The *regionID* field contains formatted information regarding key parameters in the fuel region and can be decoded as *AABBCCDDXX* where:

AA = base region ID
BB = maximum summer region RVP value (pre-2021)[d]*, or 00 for national default*[e]
CC = absence of RVP waiver, where 01 indicates no waiver
DD = minimum ethanol level in volume percent (vol%)
XX = reserved for future use

The full set of the 25 regionID values used in MOVES are shown in Table 3-1. Base region IDs comprised of two digits indicate a reformulated gasoline (RFG) area. The maximum summer RVP refers to the maximum Reid Vapor Pressure, which is a measure of the volatility of the fuel. Local air agencies may set a limit on vapor pressure of the gasoline fuel to reduce evaporative emissions of volatile organic compounds. A value of "00" indicates that the region is using the federal RVP limit.

The RVP waiver refers to the 1.0 psi RVP allowance for gasoline containing ethanol at 9 to 10 volume percent. For example, for a region with a summer RVP standard of 7.8 psi, the actual RVP limit for an E10 fuel in the market would be 8.8 psi. Not all fuel regions allow for the 1.0 psi fuel waiver; for example, a State Implementation Plan (SIP) may withhold the 1.0 psi waiver to help meet air quality goals. Thus, the presence or absence of an RVP waiver is part of each region definition. Note that, for CY 2021 and later, emission calculations are based on actual RVP values taken from survey data, which are typically 0.2 to 0.4 psi below the limit.

The minimum ethanol content parameter indicates the minimum ethanol level that has historically been required either by RFG or a local fuel program. The RFG oxygenate requirement was lifted by the Energy Policy Act of 2005, and the ethanol content values used in emission calculations use measurements from survey data. However, the oxygenate parameter in RFG regionIDs has been retained for consistency with earlier versions.

[d] The RFG program's volatility limit was simplified in 2021 to move away from an emission performance standard based on the Complex Model to instead apply an RVP cap of 7.4 psi. This is reflected in the fuel formulations, but the regionID values were not modified.

[e] During the summer ozone season, the Clean Air Act limit of 9.0 psi applies to all gasoline in the contiguous 48 states unless modified by the 1-psi E10 waiver (nearly all gasoline currently), RFG limits, or other local RVP control programs. During the shoulder and winter seasons, volatility limits are set by ASTM and are focused on optimizing vehicle performance.

Table 3-1. RegionID values in MOVES (all calendar years).

Region ID	Base Region ID#	Base Region Name	Maximum Summer RVP (psi) or 0.0 for National Default	E10 RVP Waiver Status (01=No 1-psi Waiver)	Minimum Ethanol Volume, %
0	0	Nationwide region [a]	0.0	01	51
100000000	1	East Coast, Caribbean	0.0	00	0
100010000			0.0	01	0
170000000			7.0	00	0
178000000			7.8	00	0
178010000			7.8	01	0
200000000	2	Midwest	0.0	00	0
270000000			7.0	00	0
278000000			7.8	00	0
278010000			7.8	01	0
300000000	3	South	0.0	00	0
370000000			7.0	00	0
370010000			7.0	01	0
400000000	4	North	0.0	00	0
500000000	5	Rocky Mountains, Pacific Northwest	0.0	00	0
578000000			7.8	00	0
600000000	6	AZ, NV, HI	0.0	00	0
678000000			7.8	00	0
700000000	7	Alaska	11.5	00	0
1170011000	11	East Coast RFG	7.4 [b]	01	10
1270011000	12	MD/VA RFG	7.4 [b]	01	10
1370011000	13	Texas RFG	7.4 [b]	01	10
1470011000	14	Midwest RFG	7.4 [b]	01	10
1570011000	15	California RFG	7.4 [b]	01	10
1670011000	16	Colorado RFG	7.4 [b]	01	10

[a] Region 0 is only used in estimating the emissions from vehicles running on high-level ethanol blends (e.g., E85). For additional details, see the MOVES fuel effects documentation. Minimum ethanol content shown here is set to match the ASTM definition of E85 products being those containing between 51-83 vol% ethanol.

[b] The value of 7.4 psi reflects the RVP limit after the 2020 fuels regulatory streamlining rule, though regionID values were not modified.

Figure 3-1 shows the mapping of all fuel regions at a county level in July 2024. These region assignments are carried forward through 2060. Additional maps are available in Appendix A.

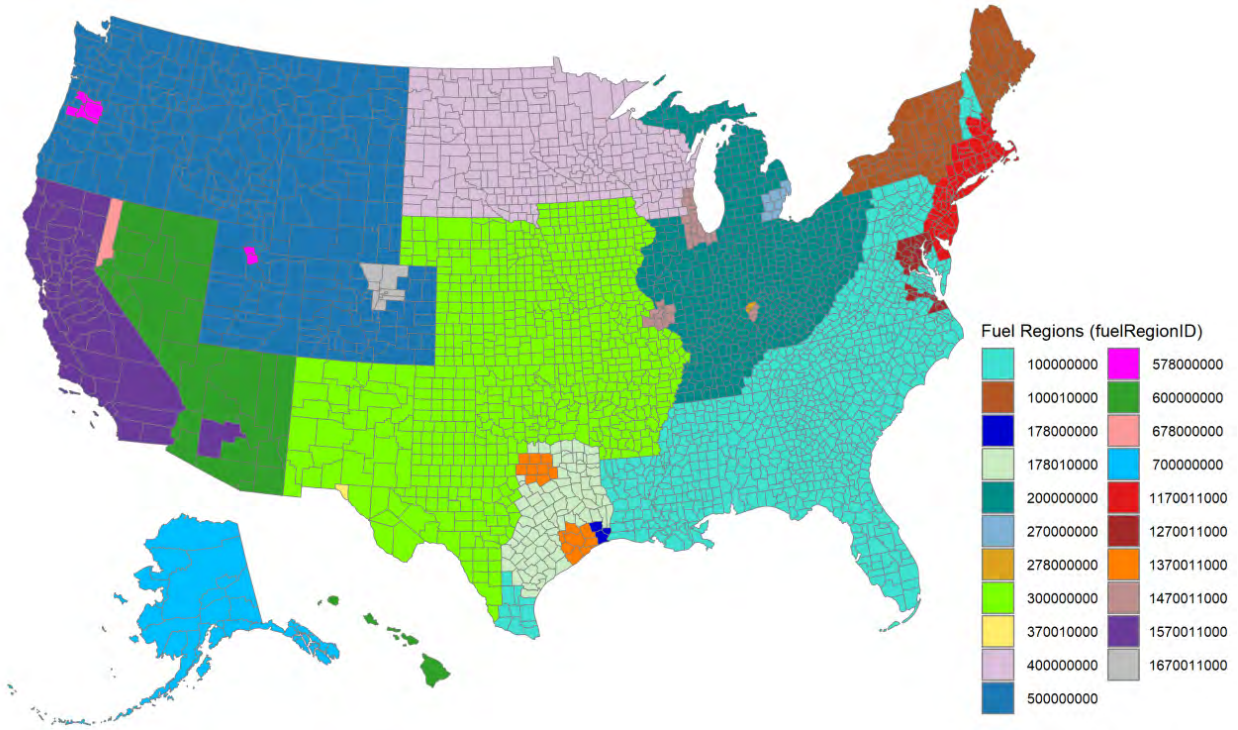

Figure 3-1. Map of MOVES fuel regions for 2024.

As mentioned above, the regionCounty table includes a fuelYearID dimension that corresponds to the calendar year and spans 1990 through 2060. This allows the model to account for changes over time in the region to which a county is assigned, for example when local volatility programs start or end. Updates in MOVES5 include removal of the summertime 7 psi requirement in the Kansas City area, ending RFG use in Maine, and addition of new RFG counties in Texas and Colorado.[6] Table 3-2 summarizes changes in local fuel programs for CY 2014 and later.[f] Additional information on local fuel programs prior to 2014 are shown in previous versions of the fuel supply documentation.[7]

[f] For CY 1990, RVP values in the MOVES gasoline fuel supply are based on ASTM volatility class limits. Historical retail survey data suggests actual 1990 RVP values were lower.

Table 3-2. Local fuel program updates for 2014 and later.[a]

Year[b]	State	Change and Data Source
2014	NC	Davidson, Forsyth, Guilford, Davie, Durham, Wake, and Granville counties move to 9 psi. https://www.govinfo.gov/content/pkg/FR-2014-05-22/pdf/2014-11911.pdf
2014	FL	All areas now at 9 psi. https://www.govinfo.gov/content/pkg/FR-2014-05-22/pdf/2014-11911.pdf
2015	AL	All areas now at 9 psi. https://www.govinfo.gov/content/pkg/FR-2015-07-02/pdf/2015-16392.pdf
2015	ME	York, Cumberland, Sagadahoc, Androscoggin, Kennebec, Knox, and Lincoln counties move to RFG. https://www.govinfo.gov/content/pkg/FR-2014-08-28/pdf/2014-20177.pdf
2016	GA	13 Atlanta metro counties move to 7.8 psi Federal gasoline from 7.0 psi "Georgia Gasoline" (Cherokee, Clayton, Cobb, Coweta, DeKalb, Douglas, Fayette, Forsyth, Fulton, Gwinnett, Henry, Paulding, and Rockdale). Remaining 32 Georgia Gasoline counties move to 9 psi. https://www.govinfo.gov/content/pkg/FR-2014-03-14/pdf/2014-05697.pdf
2016	NC	All areas now at 9 psi. https://www.govinfo.gov/content/pkg/FR-2015-08-17/pdf/2015-20243.pdf
2017	OH	All areas now at 9 psi. https://www.govinfo.gov/content/pkg/FR-2017-04-07/pdf/2017-06889.pdf and https://www.govinfo.gov/content/pkg/FR-2017-02-15/pdf/2017-03082.pdf
2017	TN	Nashville area (Davidson, Rutherford, Sumner, Williamson, and Wilson) moves to 9 psi. https://www.govinfo.gov/content/pkg/FR-2017-06-07/pdf/2017-11700.pdf
2018	LA	Louisiana parishes (Beauregard, Calcasieu, Jefferson, Lafayette, Lafourche, Orleans, Pointe Coupee, St. Bernard, St. Charles, St. James, and St. Mary) move to 9 psi. https://www.gpo.gov/fdsys/pkg/FR-2017-12-26/pdf/2017-27628.pdf
2018	KY	Cincinnati area (Boone, Campbell, and Kenton) moves to 9 psi, effective July 1, 2018. https://www.govinfo.gov/content/pkg/FR-2018-04-02/pdf/2018-06538.pdf
2018	TN	Shelby county moves to 9 psi. https://www.govinfo.gov/content/pkg/FR-2017-12-22/pdf/2017-27630.pdf
2019	PA	All areas now at 9 psi. https://www.govinfo.gov/content/pkg/FR-2018-12-20/pdf/2018-27481.pdf
2019	LA	All areas now at 9 psi. https://www.govinfo.gov/content/pkg/FR-2018-10-24/pdf/2018-23247.pdf
2020	GA	All areas now at 9 psi. https://www.govinfo.gov/content/pkg/FR-2019-05-14/pdf/2019-09929.pdf
2021	MO	Kansas City area now at 9 psi. https://www.govinfo.gov/content/pkg/FR-2021-03-12/pdf/2021-04764.pdf
2021	KS	All areas now at 9 psi. https://www.govinfo.gov/content/pkg/FR-2021-03-12/pdf/2021-04763.pdf
2022	ME	RFG requirement no longer in effect. All counties revert to 9 psi with no 1 psi waiver. https://www.govinfo.gov/content/pkg/FR-2022-08-26/pdf/2022-18320.pdf
2024	TX	Expansion of RFG in the Dallas-Fort Worth area to include Ellis, Johnson, Kaufman, Parker, Rockwall and Wise counties. https://www.govinfo.gov/content/pkg/FR-2023-10-12/pdf/2023-22532.pdf
2024	CO	New RFG area covers counties previously at 7.8 psi: Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas, Jefferson, Larimer, Weld. https://www.govinfo.gov/content/pkg/FR-2023-10-12/pdf/2023-22532.pdf

[a] Pressure values are Reid Vapor Pressure (RVP). Ethanol blending waiver of 1 psi should be added to all RVP values shown here unless otherwise specified. RFG is federal reformulated gasoline.
[b] Changes shown were effective at the start of the calendar year (for RFG) or the summer volatility control season unless otherwise specified.

4. **Development of Gasoline Property Values**

Since MOVES2014, gasoline fuel properties in the default fuel supply have been based on thousands of samples collected each year as part of EPA's gasoline compliance program. A list of the properties used in MOVES fuel formulations is summarized in Table 4-1. Appendix B presents average gasoline formulation trends over years 2000-2025.

Table 4-1. Fuel data used in MOVES regional fuel property methodology.[g]

Property data in vol%: Aromatics, Benzene, E200, E300, Ethanol, Olefins.
Other property data: Oxygen (mass%), RVP (psi), Sulfur (ppm mass), T50 (°F), T90 (°F).

MOVES also records other fuel properties by fuel subtype for use in calculations of fuel consumption and carbon dioxide emissions. These properties include carbon content, energy content and fuel density. For more information see Table 1-1.

In MOVES4 and prior versions, the primary data source had been fuel production records submitted by refiners, blenders, and importers, covering approximately thirty-thousand batches per year.[h] A limited amount of retail survey data was also available for a number of cities, but the wide batch-to-batch variation in fuel properties of the production data (Figure 4-1) illustrates that relying on a limited survey would not provide results sufficiently representative of the mean fuel quality in each region.[i,8] Thus, regional fuel properties were estimated by volume-weighting the production data using information about the distribution networks.

[g] T50 and T90 refer to the temperature at which 50 vol% and 90 vol% of the fuel has evaporated. For other fuel parameter definitions, see the *EPA Fuel Trends Report* cited in the references.
[h] These compliance reports are considered Confidential Business Information (CBI) and cannot be provided to the public in raw form. The data analysis and aggregation are discussed in more detail in Section 5.
[i] Further analysis of this production data is available in the *EPA Fuel Trends Report* cited in the references.

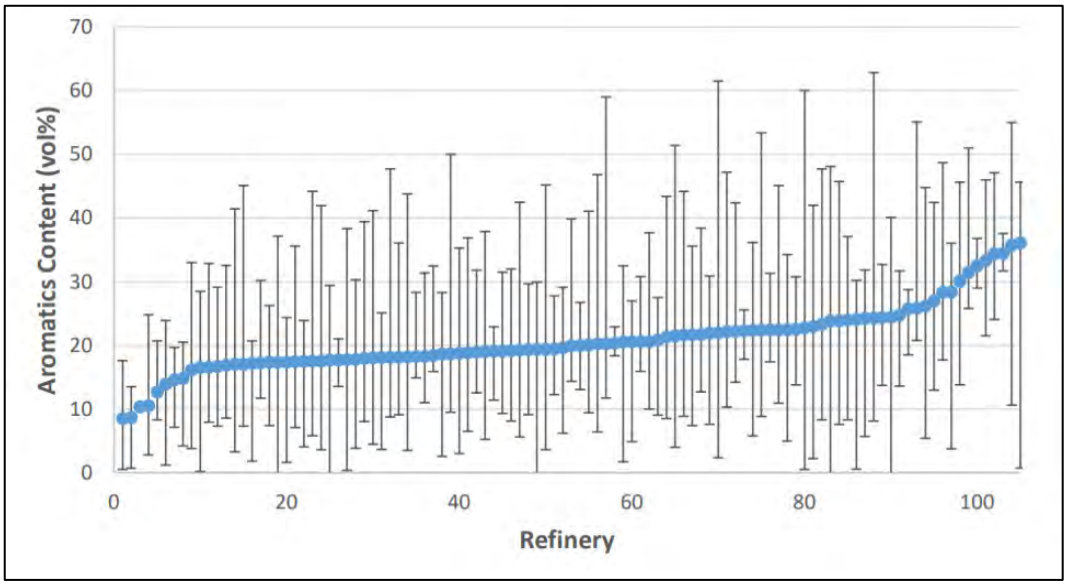

Figure 4-1. Aromatics maximum, minimum, and mean by U.S. refinery in 2016 for RFG (includes ethanol blending) and CG (not adjusted for ethanol blending).

The 2020 Fuels Regulatory Streamlining rule limited the batch-by-batch fuel production data collected from refiners, importers, and blenders to just sulfur, benzene, and RVP while at the same time it expanded the retail survey program to cover all gasoline nationwide.[j] Beginning in January 2021, gasoline samples are being collected from each state proportional to its share of national gasoline sales, and within the state accounting for population density and transportation corridors.[k] The dataset includes all octane grades, sampled proportional to their sales share. Sampling activity occurs approximately quarterly in each area, though not on the same dates across all areas. Figure 4-2 shows aromatics data from Los Angeles County over a three-year period, illustrating significant variation across the retail market. While this program does not account for every batch of fuel, it is a large, statistically-designed survey that has the advantage of capturing fuel properties at the point of use. Thus, starting with CY 2021, the MOVES gasoline fuel property values for each region were redeveloped based solely on this retail survey data. A comparison of the MOVES4 and MOVES5 fuel formulations is available in Appendix C.

[j] See 85 Fed. Reg 78412 for more details on the 2020 EPA Fuels Regulatory Streamlining rule. Previously, EPA had collected retail survey data only from RFG areas. There is additional information on the RFG Survey Association website at https://www.rfgsa.org/methodology.html.

[k] California sales volumes are down-weighted by 50% in the sampling scheme to allocate samples across the U.S. more broadly.

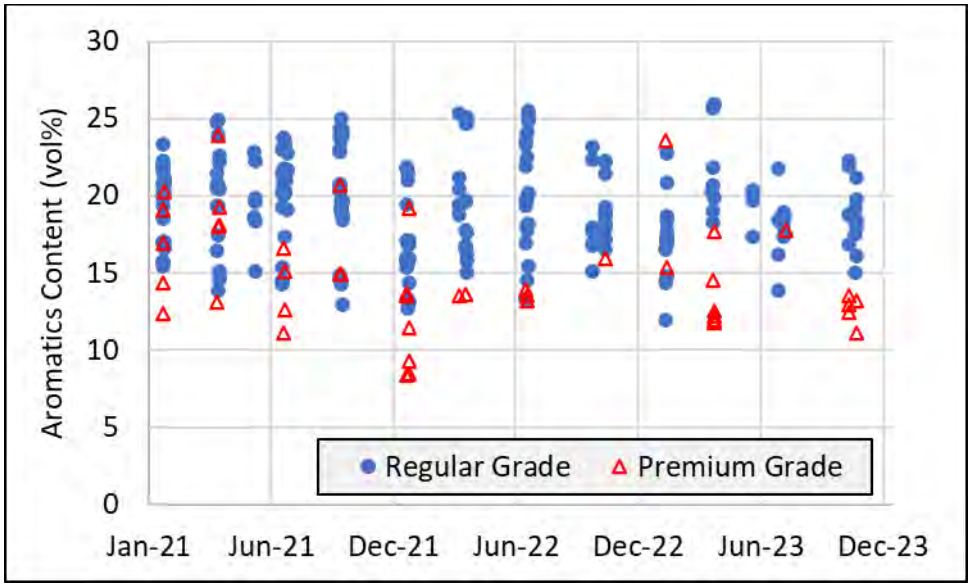

Figure 4-2. Range of aromatics content in retail gasoline samples in Los Angeles County.

Table 4-2 shows a high-level summary of sources of fuel formulations in MOVES5. The remainder of Section 4 describes in more detail the development of specific portions of the fuel supply.

Table 4-2. Sources of fuel formulations and market shares in the MOVES5 fuel supply by calendar year and ethanol blend level.[1]

Calendar Year →	1990-2013	2014-2020	2021+
E0	MOVES2014	Computed E0 properties from local E10 formulations using Fuel Wizard factors	
E10	MOVES2014 with updated distillation values	MOVES4	Retail survey data
E15	None	Splash-blends computed from local E10 properties (winter season only in 2014-2018)	
Ethanol Market Share	MOVES2014	100% E10 with E0 and E15 formulations available in the fuel supply	

[1] Table 4-4 presents more details for years 2014-2020 in a similar format.

4.1 Formulations for 2013 and Earlier

For years 1990-2006, refinery batch data was unavailable for use in MOVES development. Thus, the fuel supply for these years in MOVES2014-and-later was produced by aggregating the county-level fuel properties in MOVES2010 (which came from a variety of sources) into new fuel regions using county VMT weightings.[9] For years 2007-2013, a large amount of gasoline batch data was available that included fuel properties as well as batch volumes, so that volume-weighted averages could be produced.[m] This analysis was performed for MOVES2014 and updated for MOVES3 and MOVES4 as described below.

4.1.1 Processing of Gasoline Batch Data

Before aggregating the batch data into fuel regions, we repaired or excluded duplicate batches or those with missing data. We also calculated missing volatility values as described in Section 4.1.2. Then we separated differing types of fuel batches for further processing. In these steps, non-ethanol and pre-blended gasolines were included in the dataset without adjustment, while blendstocks for oxygenate blending (BOBs) had properties adjusted to account for ethanol that would be added downstream from the refinery gate. This was generally done by an averaging (*i.e.*, dilution) calculation because the properties reported were for the sub-grade hydrocarbon, which is splash-blended with ethanol at the destination terminal prior to local distribution. This adjustment is described in more detail in the introduction section of EPA's Fuel Trends Report.[8]

After these steps, we had between twenty and thirty-five thousand usable batch records for a given year, with no fuel region being represented by less than one thousand batches. The fuel property data were then aggregated by fuel region (see Section 2), using fuel batch size as a weighting factor. Initially, fuels were aggregated into four seasonal categories, including summer, winter, and two transitionary 'shoulder' seasons. After reviewing the results of these categories, we determined that there was not adequate data (<100 batches for some regions) on fuel properties other than RVP and distillation to determine specific shoulder season values. Thus, two aggregation seasons were used for this dataset: summer (May through September) and winter (January, February, March, April, October, November, and December). The RVP values for shoulder season (April and October) were set to intermediate values between summer and winter, and distillation values adjusted using the factors described in Section 7, Table 7-2. Other fuel properties were set to winter values for the shoulder months for CY 2013 and earlier.

To determine ethanol content of fuels in years prior to 2014, we used information from the Annual Energy Outlook report published by the U.S. Energy Information Administration (EIA) in conjunction with the overall fuel energy requirements computed by MOVES to calculate the E10 market share for years 2013 and earlier.[10, 11]

For sulfur in years prior to 2011, we used the gasoline batch data as the source of the fuel sulfur content. However, the data suggests that over 80 percent of batches in the 2011 database consist of blendstock (CBOB/RBOB) for downstream ethanol blending. Therefore, for CY 2011 and later, when making adjustments to include the addition of ethanol, we did not include dilution effects on sulfur, but instead set sulfur to 30 ppm consistent with full phase-in of Tier 2 sulfur

[m] The batch datasets included all grades of gasoline, so that the properties of mid-grade and premium fuels were weighted into the averages according to their production volumes.

program.[12] Benzene, regulated under the MSAT2 standards,[13] was also not adjusted for dilution, under the assumption that refiners were accounting for the ethanol content when adjusting their benzene levels.

The EPAct emissions models, implemented in MOVES2014 to estimate fuel adjustments to emissions in 2001 and newer vehicles, were built specifically around ethanol blends and cannot be used to compute emission impacts of other oxygenates such as MTBE (methyl tertiary-butyl ether) Thus, in MOVES2014, any MTBE was replaced with ethanol at a 1:1 volume ratio in order to provide an approximation of fuel effects across the range of model years (no other fuel properties were adjusted besides the oxygenate). More details on the EPAct models are available in the MOVES3 Fuel Effects report.[14]

As a final step, these production-based fuel properties in each region were weighted together with incoming regional transfers of gasoline produced elsewhere, using data from EIA's Petroleum Supply Annual reports, in an effort to make them more representative of fuel being consumed in the region.[15] This technique was developed for benzene in the MSAT2 rulemaking analysis and is described in more detail in Chapter 6.10.1.3 of the associated regulatory impact analysis.[16]

4.1.2 Revision of Volatility Parameters

The underlying gasoline batch data used in generating the fuel supply contains E200/E300 values for the vast majority of batches, consistent with reporting requirements, and T50/T90 for only a subset. The T-number equivalents are needed for emission adjustments and were initially calculated using the correlations in Equation 4-1 and Equation 4-2 (derived from E0 gasoline data as part of the Complex Model).[17]

$$T50 = 2.0408 \times (147.91 - E200) \quad \textbf{Equation 4-1}$$

$$T90 = 4.5454 \times (155.47 - E300) \quad \textbf{Equation 4-2}$$

A subsequent analysis of more recent market survey data suggested that the correlation between E and T values should be updated for E10 fuels. Figure 4-3 shows a correlation analysis developed from 2017 and 2018 Alliance for Automotive Innovation (AAI) surveys for E10 regular grade gasoline for both conventional and reformulated gasolines.[18]

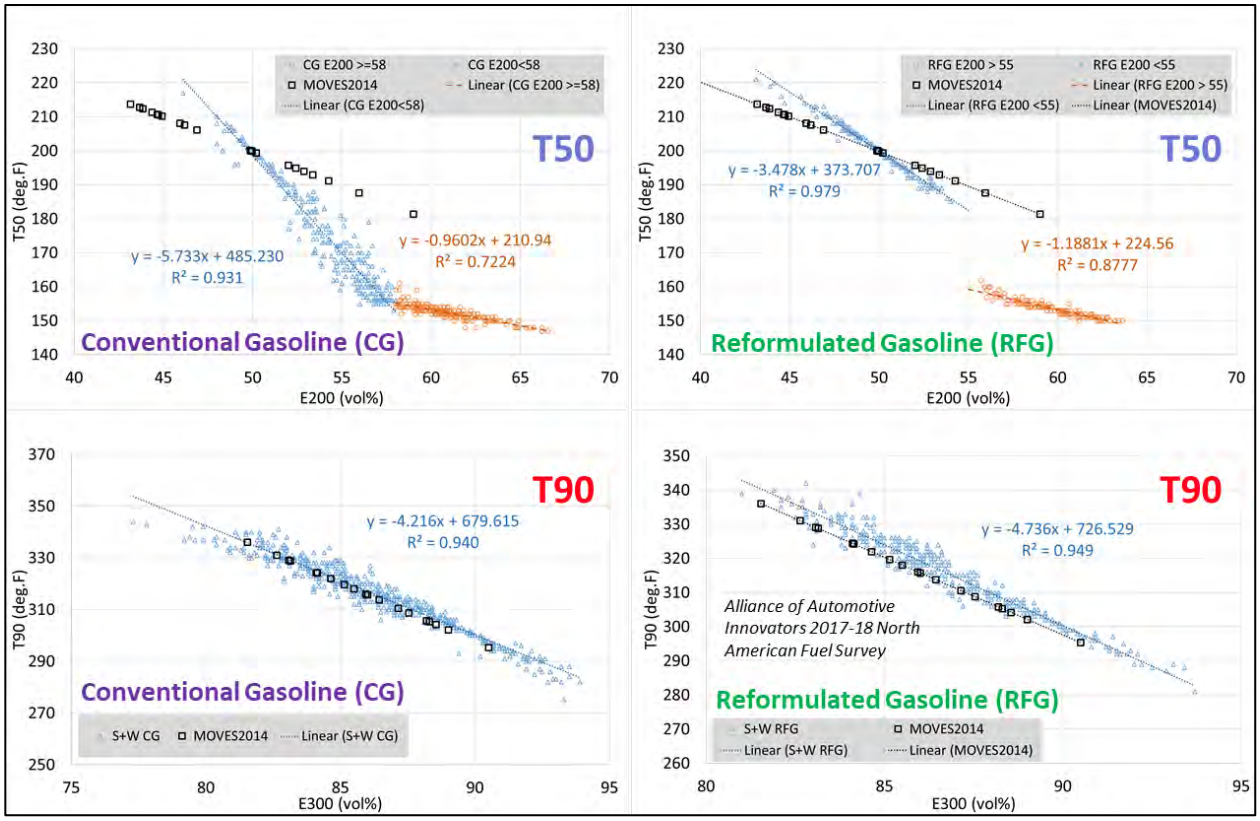

Figure 4-3. Derivation of updated T50 and T90 correlations for regular grade E10 gasoline. Conventional gasoline are the left plots and reformulated are on the right.

The T50 correlations show discontinuities at E200 values of approximately 58 vol% for CG and 55 vol% for RFG, reflecting seasonal differences in fuel formulation. Thus, for T50, we fit two separate correlation equations (orange and blue points) for both CG and RFG. While there was little change in the T90/E300 correlation from the historical E0-based relationship, updated equations were also implemented in MOVES3 and later. These updated correlations, shown in Equation 4-3 through Equation 4-8, were used to generate new T-numbers for all E10 formulations in the fuel supply, including historical fuels.

$$\text{CG T50} = 485.230 - 5.733 \times \text{E200} \quad (\textit{where E200} < 58) \qquad \textbf{Equation 4-3}$$

$$\text{CG T50} = 210.94 - 0.9602 \times \text{E200} \quad (\textit{where E200} \geq 58) \qquad \textbf{Equation 4-4}$$

$$\text{CG T90} = 679.615 - 4.216 \times \text{E300} \qquad \textbf{Equation 4-5}$$

$$\text{RFG T50} = 373.707 - 3.478 \times \text{E200} \quad (\textit{where E200} < 55) \qquad \textbf{Equation 4-6}$$

$$\text{RFG T50} = 224.56 - 1.1881 \times \text{E200} \quad (\textit{where E200} \geq 55) \qquad \textbf{Equation 4-7}$$

$$\text{RFG T90} = 726.529 - 4.736 \times \text{E300} \qquad \textbf{Equation 4-8}$$

4.1.3 Revision of California Fuel Properties

The batch data reports available to EPA do not contain data for gasoline sold in California, as certification of those batches is handled by state authorities. Thus, beginning with MOVES3, California fuel properties were updated based on AAI surveys collected in Los Angeles and San Francisco annually starting in CY 2000.[18] To cover the earlier years, 1990 and 1999 values duplicate the 2000 properties. After review of data sources available at the time, we felt this would produce the most accurate and consistent results.

4.1.4 Revision of Ethanol Blend Market Shares

In MOVES2014, market shares of E0 and E10 ethanol blends were set based on batch data reports, as described in Section 4.1.1 above. Beginning with MOVES3, market shares of ethanol blends were simplified to reflect 100% E10 in all regions for 2012 and later. Given the difficulty of estimating the sales volumes and locations of E0 (non-ethanol fuel) and E15 ethanol blends, both of which are very small relative to E10, their market shares have been set to zero for 2012 and later.

4.2 Formulations for 2014-2020

Beginning with MOVES3, we generated a new gasoline fuel supply for CY 2014 and later. For years 2014-2020, the formulation development drew on batch data from 2015 and 2016 and applied the analysis methodology described in Section 4.1.1 through 4.1.4.[n] One notable difference was that all shoulder season properties were set to values intermediate between summer and winter in each region.

To produce CY 2014, 2015 and 2017-2020 fuel supplies from the 2015-16 batch dataset, adjustments were made by applying year-by-year relative difference factors computed from publicly-available refinery batch data summaries on EPA's website.[19] This analysis computed national-scale adjustments by season, year, CG/RFG, and fuel property, and did not attempt to adjust for the ethanol level of the batch data. These adjustment factors were generally small (i.e., a few percent) and the ratio of BOB to finished gasoline was not changing greatly from year to year.

With MOVES3, the CY 2014-2020 sulfur levels were updated to follow the declining batch data trend as the Tier 3 sulfur requirement was phased in.[20] MOVES4 brought additional updates to 2018-2020 fuel formulations based on refinery batch data made available since MOVES3.

After considering the effects of the 2020 pandemic on refinery operations, a decision was made in MOVES4 to use national aggregate sulfur data for CY2020 formulations as shown in Table 4-3. Other 2020 fuel property values were computed from 2019 values by applying the Fuel Wizard factors (described in Section 7) for the sulfur changes observed from 2019 to 2020.

[n] For California fuels, the survey-based approach described in Section 4.1.3 was used in CY 2014-2016 (the range of data available at the time of analysis), with formulations for years 2017-2020 being duplicated from 2016.

Table 4-3. Gasoline sulfur levels for 2020 for all regions except California.

	Summer	Winter
Conventional	7.15 ppm	8.12 ppm
Reformulated	7.36 ppm	8.70 ppm

Finally, E0 and E15 formulations were developed for CY 2014 and later (E15 summer blends begin in 2019) as described in the next subsection. While their market share was set to zero in the fuelSupply table, the formulations were computed to give users a simple and consistent way to model these fuels if desired. Table 4-4 summarizes development of the CY 1990-2020 fuel supply.

Table 4-4. Sources of fuel property values for the 1990-2020 fuel supply by calendar year and ethanol blend level

Year →	2014	2015	2016	2017	2018	2019	2020
E0 formulations	E0 properties computed from local E10 formulations using Fuel Wizard (i.e., reverse match-blending)						
E10 formulations	Adjusted 2016 properties using batch data and any local RVP requirements		Refinery batch data	Adjusted 2016 properties using batch data and any local RVP requirements			Sulfur set to 2020 batch levels; other properties derived from 2019 values using Fuel Wizard
E15 formulations	Splash-blend properties computed from local E10 formulations for winter and shoulder seasons only					Splash-blend properties computed from local E10 formulations year-round	

4.2.1 Development of E15 and E0 Formulations

E15 properties were computed assuming splash blending from the local E10, consistent with the extension of the 1 psi waiver to E15. This is the most likely scenario until E15 volumes are large enough to warrant their own sub-grade blendstocks. Thus, the aromatics, sulfur, benzene, and olefin values for E15 were computed as 0.95 times the E10 property value based on mathematical dilution.[o] Effects on distillation properties were estimated by comparing regular grade E10 and E15 values from Appendix A of the 2010 API blending study [21] (presented in Figure 4-4 and Figure 4-5).

[o] This computation assumes there is a negligible amount of aromatics, sulfur, and air toxics in denatured fuel ethanol. Denatured fuel ethanol typically contains about 2% of a hydrocarbon mixture that is similar to market gasoline but can vary in composition.

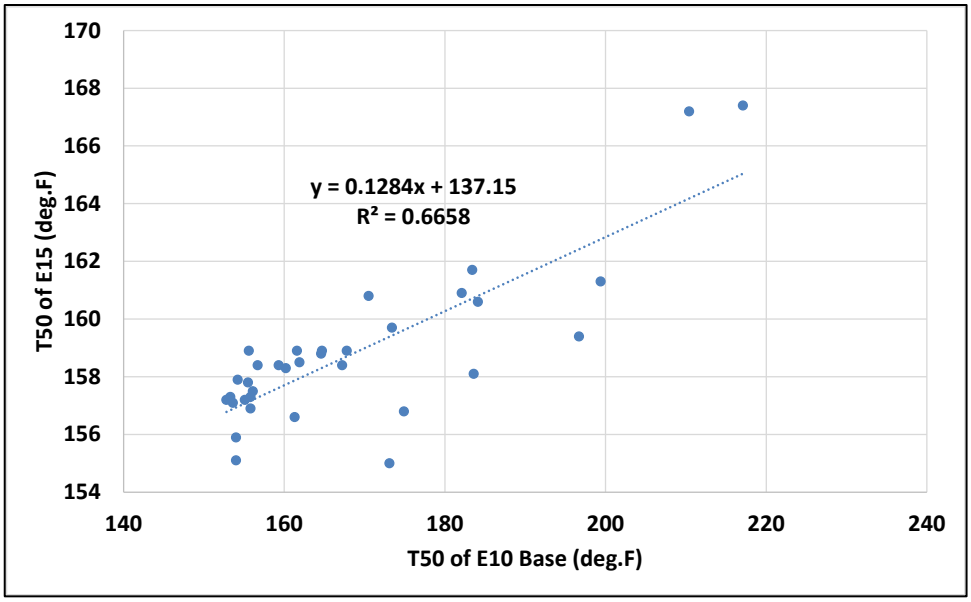

Figure 4-4. T50 effect of splash blending E15 from E10 in 2010 API blending study.

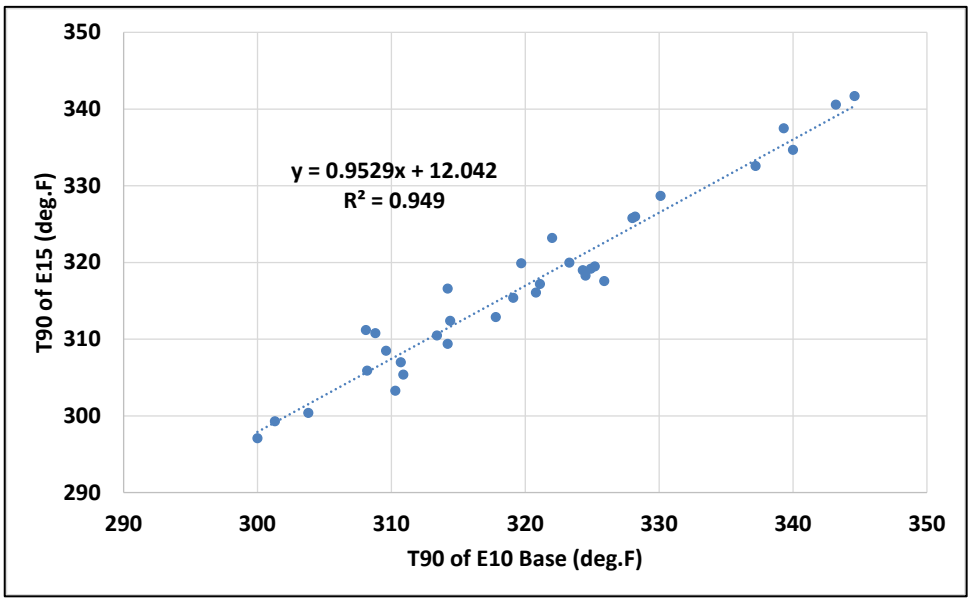

Figure 4-5. T90 effect of splash blending E15 from E10 in 2010 API blending study.

The correlations shown in Figure 4-4 suggests that adding 5% ethanol to an E10 blend reduces and compresses the T50 temperature into a narrow range between 150-162°F. The effect on T90 is much more moderate (Figure 4-5), reducing the E10 value by a few degrees. RVP was reduced by 0.15 psi for the E15 blend based on results of the same study.

$$T50_{E15} = 137.15 + 0.1284 \times T50_{E10} \quad \textbf{Equation 4-9}$$

$$T90_{E15} = 12.042 + 0.9529 \times T90_{E10} \quad \textbf{Equation 4-10}$$

Populating the fuelFormulation table with the E15 splash blends requires E200 and E300 values,

so the reverse of the earlier conversions of the batch data was required here. Since there is no large survey of market E15 fuels to draw upon, the same AAI survey dataset used for the E10 correlations was used. The earlier E300/T90 relationship was simply inverted, but for E200/T50 the correlation was refit to a limited E200 range of 55-60 vol% expected to be most applicable to E15 fuels (Figure 4-6).[p]

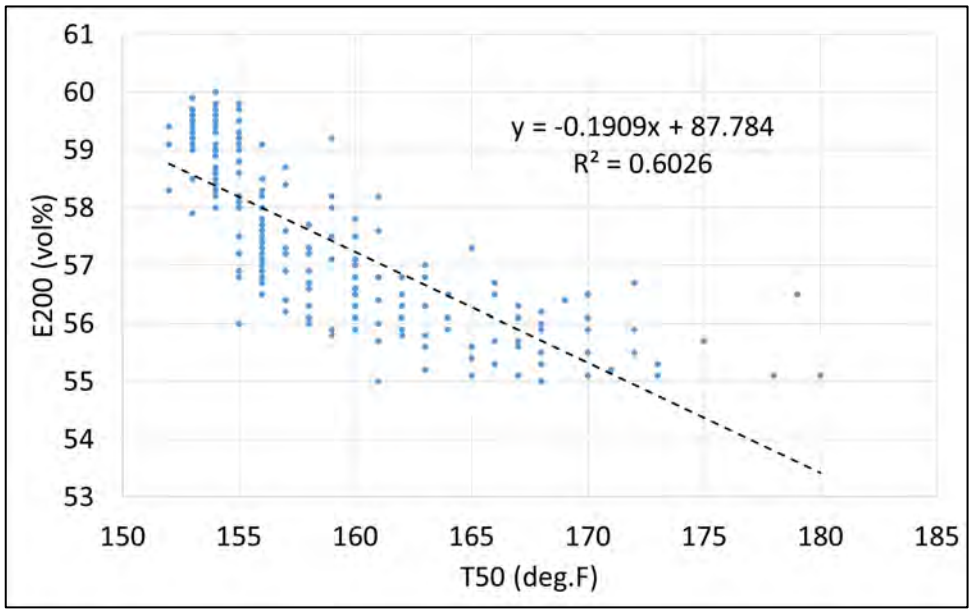

Figure 4-6. E200 to T50 correlation for E15 fuels based on AAI 2017-18 market surveys.[18]

Results of this analysis are shown in Equation 4-11 and Equation 4-12.

$$E200 = 87.784 - 0.1909 \times T50 \qquad \textbf{Equation 4-11}$$

$$E300 = 156.69 + 0.2229 \times T90 \qquad \textbf{Equation 4-12}$$

Producing E0 properties for each region based on the local E10 required a reverse match-blending computation to make up for ethanol's octane. The updated Fuel Wizard factors (discussed in more detail in Section 7) were applied for all properties except RVP and T50/T90. RVP was adjusted downward by 1 psi except in areas without the 1-psi waiver. The distillation values of T50/T90 were computed using the E0 correlations to E200/E300 shown in Equation 4-1 and Equation 4-2.

4.3 Formulations for 2021 and Later

In MOVES5, gasoline formulations for CY 2021 and later were produced from an analysis of approximately 16,500 retail survey samples collected across the country between January 2021

[p] The emission adjustments for vehicle model years in which E15 can legally be used are computed based on T50 and T90 as input parameters. The E200/E300 values were computed here for the sake of completeness and academic interest; we don't expect them to be used in any emission calculations in the public versions of the model.

and December 2023.[q] These were aggregated into a single dataset from which seasonal averages were produced for each fuel region, with approximately 40% of the samples representing each summer and winter, and the remainder from shoulder periods (Table 4-5). Since fuel distribution networks are relatively stable, we chose to combine multiple years of data to increase confidence in the means. In the current application of this data to years 2021 and later, no attempt is made to capture year-by-year variations in fuel properties.[r]

Table 4-5. Distribution of retail samples by region and season.

	Number of Samples by Season[a]		
RegionID	**Summer**	**Winter**	**Shoulder**
100000000	1297	1285	708
100010000	606	761	62
178000000	8	22	0
178010000	254	241	8
200000000	851	789	485
270000000	89	46	68
278000000	0	11	11
300000000	567	628	291
370010000	16	0	0
400000000	297	379	105
500000000	598	619	101
578000000	121	154	36
600000000	195	191	88
678000000	16	27	0
700000000	16	14	9
1170011000	664	652	546
1270011000	106	147	1
1370011000	178	160	120
1470011000	212	192	72
1570011000	542	638	288
Totals	**6633**	**6956**	**2999**

[a] Summer months are May through September, shoulder months are April and October.

In three regions with zero or very small sample counts (<10) in summer or winter, formulations were determined as follows:

- Region 178000000 (Beaumont, TX area) summer fuel: RVP level was set at 0.4 psi

[q] There is additional information on the data collection process at the RFG Survey Association website, https://www.rfgsa.org/methodology.html.

[r] The transition to survey data in MOVES5 resulted in higher gasoline sulfur levels in most regions in 2021 and later. Sulfur levels in prior model versions were based on refinery gate data with assumptions about the sulfur content of ethanol added downstream. The updated values better reflect the actual sulfur contribution of all additives as well as any cross-contamination from other products in the distribution system.

below the nominal standard of 8.8 psi.[s] Other properties were estimated by assuming 1.5% butane is added to region 178010000 fuel (7.8 psi) in adjacent counties to boost RVP by 1 psi.[t, 22] Distillation parameter values were estimated by averaging regions 100010000 and 578000000, which have similar fuel.

- Region 278000000 (Indiana counties in Louisville, KY area) summer fuel: Indiana counties use this 8.8 psi fuel while nearby KY counties uses region 1470011000 RFG. Thus, properties for 278000000 were determined from the KY fuel by assuming addition of 1.9 vol% butane (adjustment from the RFG RVP to 8.4 psi), with other properties adjusted accordingly. Distillation parameters were mirrored from region 178000000, which has similar fuel.
- Region 370010000 (El Paso, TX area) winter fuel: This county was assumed to use the same fuel as the surrounding area in the winter, so properties were set equal to base region 300000000.

Since it is focused on regulatory requirements, the survey only measures RVP during summer months when EPA volatility controls are in place. Therefore, winter RVP values for CY 2021 and later were estimated by reviewing several years of data from the Auto Innovators' North American Fuel Survey.[18] This data shows that winter RVPs are relatively consistent across the continental U.S. at around 13.5 psi in most areas, with levels about 1 psi lower in California and up to 1 psi higher in the upper Midwest and Alaska.

Beginning in MOVES3, shoulder season properties were computed as the mean of summer and winter properties, which is representative of the process of converting tanks and distribution lines over from one season's fuel to the next. While we have a considerable amount of survey data from the shoulder season, in nearly all regions the number of samples is significantly less than for winter and summer seasons. Therefore, a threshold of 100 samples was set, above which the fuel formulation values would be derived from the survey data, and below which the formulation would be computed by averaging the summer and winter values. This arrangement resulted in eight regions with survey properties, and twelve with summer-winter averages. RVP values were computed by average for all regions since surveys do not collect this parameter outside the summer season.

A new fuel region (1670011000) was added starting in CY 2024 to accommodate the change to RFG in the Denver metropolitan area. Since there was no historical data available for this formulation at the time MOVES5 was being developed, properties were estimated as follows. For summer, RVP and distillation values were set to the average value observed in other RFG regions (which fall in a relatively narrow range). Other properties were computed from the region 578000000 formulation, which had previously been used in these counties, by assuming a total of 5.8 vol% combined butane and pentane would need be removed to accomplish the

[s] In earlier versions of MOVES, summer RVP levels in-use were assumed to be at the regulatory limit. An assessment of the latest survey data shows a median compliance margin of 0.40 psi for areas with RVP > 8 psi, and 0.24 psi for RFG areas. These values have been implemented in MOVES5 for 2021 and later.

[t] Adding and removing butanes (and pentanes) is a common way for fuel producers to adjust volatility. The impact of butane addition or removal on RVP will vary depending on the starting RVP and overall volatility profile of the fuel. The estimate of 1.5 vol% butane per psi RVP is described in the cited memo.

required reduction in RVP.[u, 22] Aromatics and olefins were adjusted upward proportionally by dividing each by the factor (1-0.058), while sulfur and benzene were left unchanged under the assumption that the producers would adjust operations to maintain their current compliance margins on these regulated parameters. Winter properties were assumed to be the same as the historical 578000000 formulation, and shoulder properties were computed as the average of summer and winter.

After development of the 2021 and later fuels, complementary E0 and E15 formulations were generated with zero market share as described in Section 4.2.1.[v] Two additional updates were made. One was to reassign all counties in the Kansas City area (in both KS and MO) to base region 300000000 for CY 2021 and later. Four counties were under a 7.0 psi summer volatility control program that ended in 2020. This update eliminates region 370000000 for future years. The other was to represent the end of the RFG program in Maine by moving all RFG counties in Maine into regionID 100010000 for CY 2022 and later.

Following these updates, Table 4-6 summarizes the assignment of fuelFormulationID (FFID) values in MOVES5.[w] Calendar year 2013 and earlier gasolines originally generated for MOVES2014b have FFID values under 3000. Formulations for 2014-2020 were assigned FFIDs in bands of 122 values according to their CY and ethanol blend level. For example, E15 formulations in year 2019 fall between 8600 and 8722. New FFIDs representing CY 2021 and later are shifted upward by adding 150 to the 2020 FFIDs. This scheme leaves gaps to allow insertion of additional formulations in the future.

Table 4-6. Gasoline FuelFormulationID numbering scheme.

	Starting FuelFormulationID		
Calendar Year	**E10**	**E0**	**E15**
1990-2013	1000, 2000		
2014	3000	3300	3600
2015	4000	4300	4600
2016	5000	5300	5600
2017	6000	6300	6600
2018	7000	7300	7600
2019	8000	8300	8600
2020	9000	9300	9600
2021+	9150	9450	9750

Appendix B presents average gasoline formulation trends over years 1990-2024.

[u] We assumed reduction of RVP below 6.7 psi would require removing pentanes at a rate of 7.5 vol% per psi RVP. These figures are discussed in more detail in the cited memo.

[v] The default fuel supply contains only non-ethanol fuels for Alaska (region 700000000), consistent with their survey data. No E10 or E15 blends are available for this region.

[w] FFID values are used in the MOVES FuelSupply, nrFuelSupply, and FuelFormulation tables.

5. Diesel, CNG, and E85 Fuels

For these fuels, we do not use regulatory compliance data as the source of the fuel properties. Data sources for each fuel type are discussed in the subsections below.

MOVES also records other fuel properties by fuel subtype for use in calculations of fuel consumption and carbon dioxide emissions. These properties include carbon content, energy content and fuel density. For more information see Table 1-1.

5.1 Diesel

MOVES uses two fuel properties when adjusting emissions from diesel vehicles: sulfur level and, for engines 2006 and older, biodiesel (methyl ester) content.[14] Sulfur levels vary by calendar year but are the same across all regions. These values are summarized in Table 5-1.

For biodiesel, the blend level is zero prior to 2011, and then 3.5 vol% for all regions between 2011 and 2020. For 2021 and later, the biodiesel blend level varies by region. Determination of biodiesel levels is described in more detail in Section 5.1.2 below.

Table 5-1. Onroad diesel sulfur and biodiesel contents in MOVES across all fuel regions.

Calendar Year	Sulfur level, ppm	Biodiesel, vol%
1990	1000	0
1999-2006	130	0
2007-2010	6	0
2011-2020	6	3.5
2021+	6	varies by region

5.1.1 Sulfur Content

Retail surveys conducted by the Alliance for Automotive Innovation[18] (referenced above for gasoline) also produce data for diesel fuel. A review of results from several states suggests there is very little regional variation, with 10th-90th percentile ranges spanning 4-10 ppm. Nationally, annual average diesel sulfur levels in this data indicate that a level of 6 ppm is representative of years 2007 and later (Figure 5-1). Thus, a value of 6 ppm is used in MOVES for CY2007 and later for all regions (including CA).

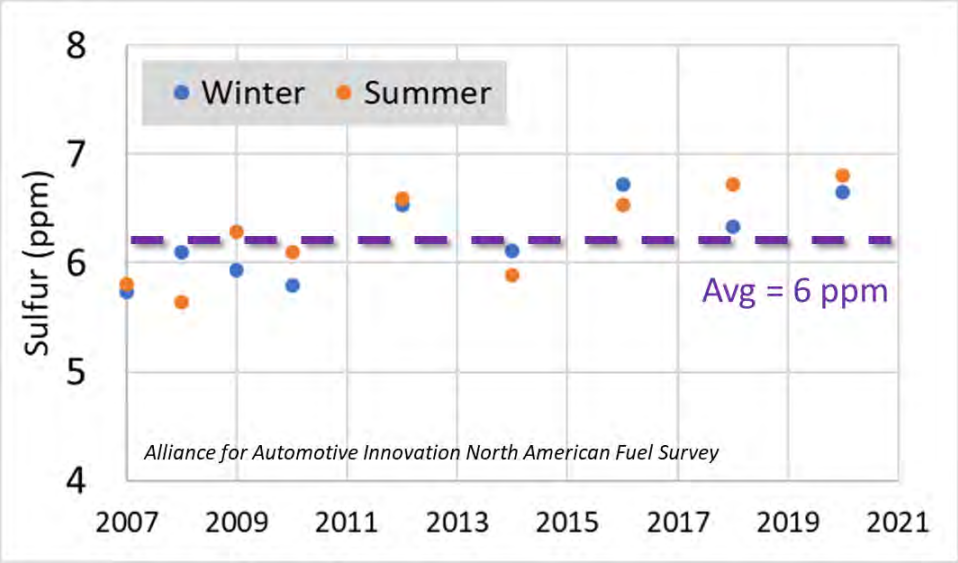

Figure 5-1. National average diesel sulfur level from market survey data.

5.1.2 Methyl Ester (Biodiesel) Content

For onroad diesel, conventional petroleum diesel (fuelSubtypeID 20) constitutes 100% of the market share for CY 1990 through 2010. Starting in CY 2011, the fuel supply shifts to 100% market share of biodiesel blend (fuelSubtypeID 21), with a vol% methyl ester level that varies by calendar year, as described below. The fuelFormulation table also contains biodiesel blend levels of 0, 5, and 20 vol%, which users may specify as alternatives.

In MOVES3 and MOVES4, a single national average blend level was used for all regions for CY 2011 and later. This value was computed using biodiesel and transportation distillate consumption data available from EIA's Monthly Energy Review.[23] For MOVES5, this approach was retained for CY 2011-2020. Figure 5-2 shows the national average blend level trend over this period, which produces an average of 3.5 vol%. The start year of 2011 was selected because this was when the national average blend level first surpassed 1 vol%.

Figure 5-2. National average biodiesel blend level computed from EIA Monthly Energy Review data, showing MOVES blend level of 3.5% for CY 2011-2020.

EIA recently expanded their State Energy Data System publications to provide biodiesel and transportation distillate consumption at the state level going back several years.[24] Based on review of trends in historical volumes, a 5-year average of 2017-2022 was chosen to represent current blend levels for 2021 and later, as this period has relatively stable blend levels in most areas. Figure 5-3 illustrates these levels at the state level.

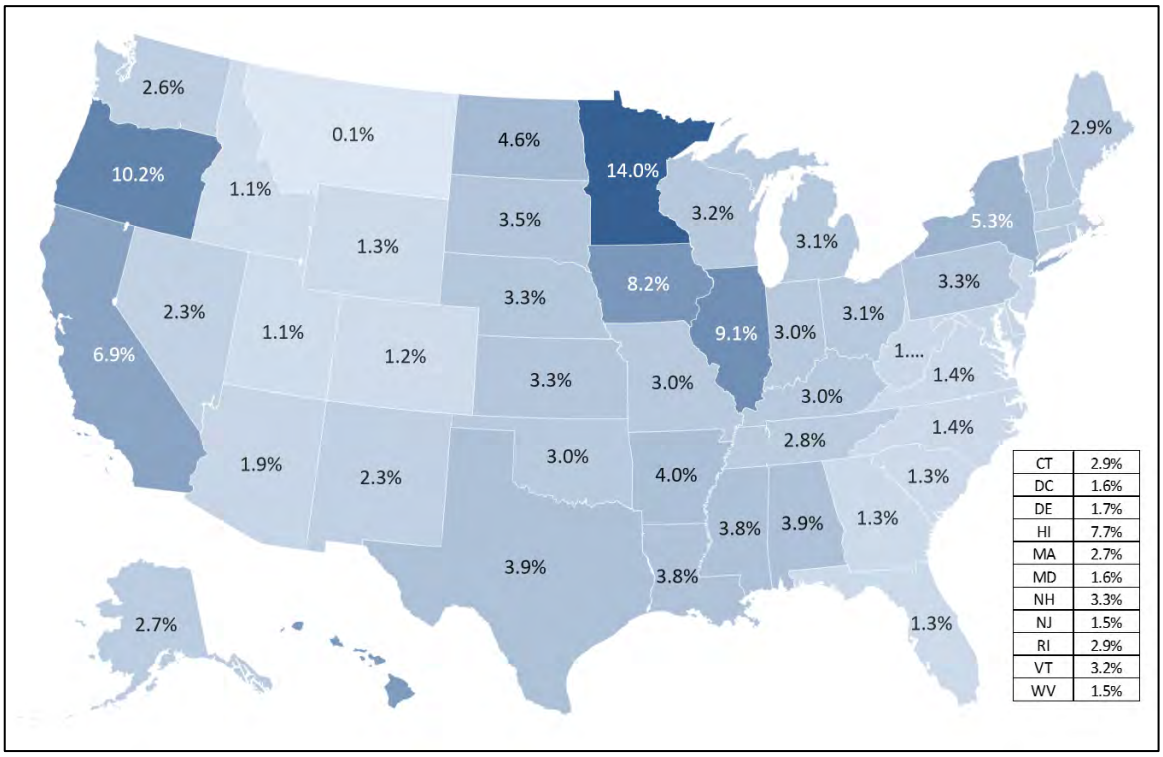

Figure 5-3. 2017-2022 average biodiesel blend level by state based on EIA data.

For CY 2021 and later, the MOVES5 fuel supply aggregates this state-level data into region-specific biodiesel blend levels for the seven gasoline base regions (shown in Table 3-1 and Figure 3-1) and California. These results are shown in Table 5-2. To implement these regional variations, eight new fuel formulations were added (25024-25031) that vary in biodiesel content but have a sulfur level of 6 ppm.

Table 5-2. Regional average biodiesel blend levels used for CY2021 and later.

Base Region	Biodiesel (kbbl/yr)[x]	Petroleum Diesel (kbbl/yr)	Blend%
1 (East Coast / Caribbean)	15,061	494,396	2.96%
2 (Midwest)	8,510	190,246	4.28%
3 (South)	5,165	128,725	3.86%
4 (North)	4,361	53,354	7.56%
5 (Rocky Mtns, Pacific Northwest)	2,746	90,277	2.95%
6 (AZ, NV, HI)	791	32,400	2.38%
7 (AK)	161	5,744	2.73%
15 (CA)	5,877	78,926	6.93%
U.S. Total	**42,671**	**1,074,070**	**3.82%**

The energy content of biodiesel is set at 42.70 (KJ/g) to represent B3.8 fuel. The energy and carbon content of the fuels are based on aggregate values that are constant across fuel subtypes as shown in Table 1-1 and documented in the MOVES GHG and energy report.[25]

5.2 Compressed Natural Gas (CNG)

MOVES assumes that CNG (fuelSubtypeID 30) used in onroad vehicles has a sulfur content of 7.6 ppm based on a CNG transit bus study documented in the MOVES fuel effects report.[14]

5.3 High-Level Ethanol Blends (E85)

As described in the Population and Activity technical report, MOVES models a subset of the vehicle fleet as "flexible fueled vehicles" (FFVs).[26] These vehicles may operate on gasoline or E85 fuel as indicated in the FuelUsageFraction table. The usage fraction represents the fraction of total fuel used by FFVs that is E85. For CY 2010-2020, we set the E85 usage fraction to 1.78% for all regions based on "Ethanol used in E85" published in Table 17 in AEO2014.[11] In MOVES5, for CY 2021 and later, we revised the fraction upward to 3.1% based on ethanol use in E85 published in AEO2023 as well as FFV registrations and VMT available through the DOE Alternative Fuel Data Center.[27,28]

The MOVES algorithms used to model the emissions from FFVs when they are operating on E85 are described in the MOVES fuel effects report.[14] The E85 algorithm uses the sulfur, benzene, and RVP values stored in the fuelFormulation table, which do not vary by region. The other property values come from the E10FuelProperties table, which includes representative E10 fuel

[x] The volumes shown represent the sum of 5-year average volumes (thousand barrels per year) for each state included in a region, so that states consuming greater volumes have higher weighting in the region average. Petroleum diesel excludes the renewable component, so it was added before computing the blend ratio.

formulations for every fuel region, CY, and month. The table also stores a national average E10 formulation as RegionID 0, which is used for national scale runs using pre-aggregation in the advanced features. The national E10 formulation was calculated as an average of the E10 fuel formulations assigned to different regions.

E85 fuel properties are summarized in Table 5-3. The sulfur and benzene values for E85 represent blending market gasoline with denatured ethanol.[y] The RVP values represent typical summer and winter seasonal targets achieved by addition of butanes or pentanes. The ethanol content of 74 vol% matches the annual average blend level used by DOE/EIA in their publications.[29]

Table 5-3. E85 fuel properties used in emission calculations for all regions.

E85 Fuel Formulation ID	Months Applied	RVP (psi)	Ethanol (vol%)	Sulfur (ppm)	Benzene (vol%)
27001	October…April	10.5	74	8	0.16
27002	May…September	7.7			

6. Nonroad Fuel Supply

The nonroad gasoline fuel supply is identical to the onroad fuel supply except that it contains no fuels with ethanol content over 10.5 vol%.

For nonroad diesel, MOVES includes two types of diesel: nonroad (fuelTypeID 23) and marine diesel (fuelTypeID 24). The only difference between them is sulfur content prior to 2014, as shown in Table 6-1. These values represent a walk-down in sulfur to meet regulatory requirements based on what was known about refining, consumption, and credit trading patterns.[30] The final sulfur level of 6 ppm for both types reflects a merger of onroad and nonroad refinery products at the end of the phase-in period, thus nonroad fuel attains the sulfur level observed in onroad fuel. Survey data suggests there is little variation in diesel sulfur levels across the continental U.S., so the 6 ppm level is applied nationwide to nonroad as in onroad fuel. Note that MOVES does not model locomotives or commercial marine vessels, so these fuels apply to railroad support equipment and recreational marine.

Nonroad CNG and liquified petroleum gas (LPG, fuelSubtypeID 40) sulfur levels are 7.6 ppm for all years, consistent with the onroad CNG sulfur level. Other properties of nonroad fuels are shown in Table 6-2. Note that fuel density is set at the fuelTypeID level, thus it is fixed across subtypes (e.g., conventional diesel and biodiesel blend).

[y] Denatured fuel ethanol is created when ethanol producers add a minimum of 2 vol% of a petroleum component to their anhydrous ethanol product. The chemical makeup of the petroleum component can vary. The properties used in MOVES represent a typical denatured ethanol.

Table 6-1. Nonroad diesel sulfur content in MOVES (ppm wt).

Calendar Year	Nonroad	Marine
1999 and earlier	2284	2640
2000	2284	2640
2001	2284	2635
2002	2284	2637
2003	2284	2637
2004	2284	2637
2005	2284	2637
2006	2242	2588
2007	1139	1332
2008	351	435
2009	351	435
2010	165	319
2011	32	236
2012	6	124
2013	6	44
2014 and later	6	6

The carbon and energy content values are stored in the MOVES default database like for onroad modeling, but density values are hard-coded in the nonroad model. Similarly, the nonroad model uses a hard-coded carbon mass fraction for diesel and gasoline of 0.87.[31, 32] More information on the sources of these values is available in the *Greenhouse Gas and Energy Consumption Rates* document.[33]

Table 6-2. Nonroad Fuel Subtypes in MOVES.[a]

SubtypeID (TypeID)	Description	Carbon Content (g/kJ)	Energy Content (MJ/kg)	Density (g/gal)
10 (1)	Conventional Gasoline (CG)	0.0196	43.488	6.237
11 (1)	Reformulated Gasoline (RFG)	0.0196	42.358	6.237
12 (1)	Gasohol (E10)	0.01982	41.696	6.237
13 (1)	Gasohol (E8)	0.01982	42.027	6.237
14 (1)	Gasohol (E5)	0.01984	42.523	6.237
20 (2)	Conventional Diesel Fuel	0.02022	42.869	7.061
21 (2)	Biodiesel Blend	0.02022	42.700	7.061
23 (23)	Nonroad Diesel Fuel	0.02022	42.869	7.050
24 (24)	Marine Diesel Fuel	0.02022	42.869	7.050
40 (4)	Liquefied Petroleum Gas (LPG)	0.0161	46.607	4.239

[a] Energy and carbon content values refer to lower heating values

7. Fuel Wizard Factors

Since MOVES2014a, the model software has included a "Fuel Wizard" tool to help users create realistic gasoline formulations that are not present in the default fuel supply. In the real world, adjusting one fuel property can produce collateral changes in other properties as a result of impacts on refining and blending processes. For example, reducing sulfur may affect aromatics and olefins, and varying RVP may affect other distillation points.

The Fuel Wizard allows a user to input a change in one of three gasoline properties (RVP, ethanol level, or sulfur level) and the tool estimates secondary fuel property changes using data from refinery modeling runs. This allows for the full emissions impact of proposed fuel changes (as part of state or local programs) to be estimated properly, including the subsequent effects of non-regulated fuel property changes. The Fuel Wizard is currently capable of creating fuels with ethanol variations between E0 and E15, sulfur from 0-30 ppm,[z] and RVP from 5-14 psi. [aa]

The Fuel Wizard is used in conjunction with the county data manager in the MOVES graphical user interface (GUI). More information on when users should use the Fuel Wizard is provided in technical guidance on the MOVES website.[bb]

The Fuel Wizard adjustments are stored in the fuelWizardFactors table and are applied in an additive way (not multiplicative factors). In MOVES2014 (a and b), the adjustments used in the Fuel Wizard were derived from refinery modeling done as part of the Tier 3 rulemaking analysis and are the same as those used in developing some portions of the default fuel supply.

In MOVES3, the ethanol blending factors were updated using the results of more recent refinery modeling work conducted to better understand the effects of biofuel blending on fuel quality and production cost. For that work, MathPro, Inc., developed and validated a calibration case to ensure key outputs aligned with observed performance of the refining sector, after which the control cases were run using petroleum and biofuels market data from EIA and other sources. A more detailed discussion of the modeling work, including the MathPro project report, and its outputs is available in the MOVES3 fuel supply documentation.[34]

Table 7-1 through Table 7-3 show the Fuel Wizard factors for changes resulting from adjusting ethanol, RVP and sulfur level, respectively. These values are unchanged since MOVES3.

[z] While the Fuel Wizard has several sulfur ranges with varying factors for secondary impacts on other fuel parameters, the 0-30 ppm range is the most relevant for current market fuels.

[aa] The Fuel Wizard doesn't differentiate between CG and RFG and can reasonably be applied to either. The underlying factors were derived from a range of refinery modeling scenarios, some of which included RFG and some of which did not. The fuel property changes produced by this tool should be understood as approximate in any circumstance.

[bb] MOVES technical guidance is available at https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#guidance

Table 7-1. Updated Fuel Wizard factors for ethanol addition (additive changes for ETOH change shown).

ETOH Change	RVP	SULF	AROM	OLEF	BENZ	E200	E300	T50	T90
Vol% to Vol%	psi	ppm	Vol%	Vol%	Vol%	Vol%	Vol%	Deg.F	Deg.F
E0 to E10 Winter	0.80	0	-1.7	1.7	-0.01	6.4	0.2	-23.8	-0.63
E0 to E10 Summer	0.90	0	-2.2	1.6	0	7.0	-0.2	-26.0	0.63
E10 to E15 Winter	-0.15	0	-0.85	0.85	-0.01	3.2	0.1	-11.9	-0.32
E10 to E15 Summer	-0.15	0	-1.1	0.80	0	3.5	-0.1	-13.0	0.32

Table 7-2. Adjustment factors for RVP reductions (additive adjustments per psi).

DESCRIPTION	SULF	AROM	OLEF	BENZ	E200	E300	T50	T90
	ppm	Vol%	Vol%	Vol%	Vol%	Vol%	Deg.F	Deg.F
1 psi RVP reduction (all seasons)	0	0	0	0	-1.26	-0.50	2.57	2.27

Table 7-3. Adjustment factors for sulfur changes (additive adjustments per ppm).

DESCRIPTION	RVP	AROM	OLEF	BENZ	E200	E300	T50	T90
	psi	Vol%	Vol%	Vol%	Vol%	Vol%	Deg.F	Deg.F
1 ppm reduction (summer)	0	-0.03	1.2	0	0	0.05	0	-0.19
1 ppm reduction (winter)	-0.02	-0.14	1.44	0	0.14	0.12	-0.50	-0.51

As with the compliance batch data, the distillation values in the refinery modeling output are in terms of E200 and E300 and need conversion to T-values. Since the Fuel Wizard uses a single entry for each parameter, the multi-region T50 correlations described in Section 4.1.2 for conventional gasoline (CG) were simplified as shown in Figure 7-1, resulting in Equation 7-1. For the E300 to T90 conversion, Equation 4-5 was used (also derived from CG data).

$$T50 = 377.34 - 3.7159 \times E200 \qquad \textbf{Equation 7-1}$$

For simplicity, the E10 to E15 factors in Fuel Wizard were calculated by taking 50 percent of the E0 to E10 change except for RVP, where the value was derived from the 2010 API ethanol blending study as described in Section 4.2.1. Note that the Fuel Wizard is not currently set up to perform splash blends. Users wanting to model emissions on E15 splash blends, a more likely scenario for the foreseeable future, should use the formulations available in the default supply, as explained in Section 4.2.1.

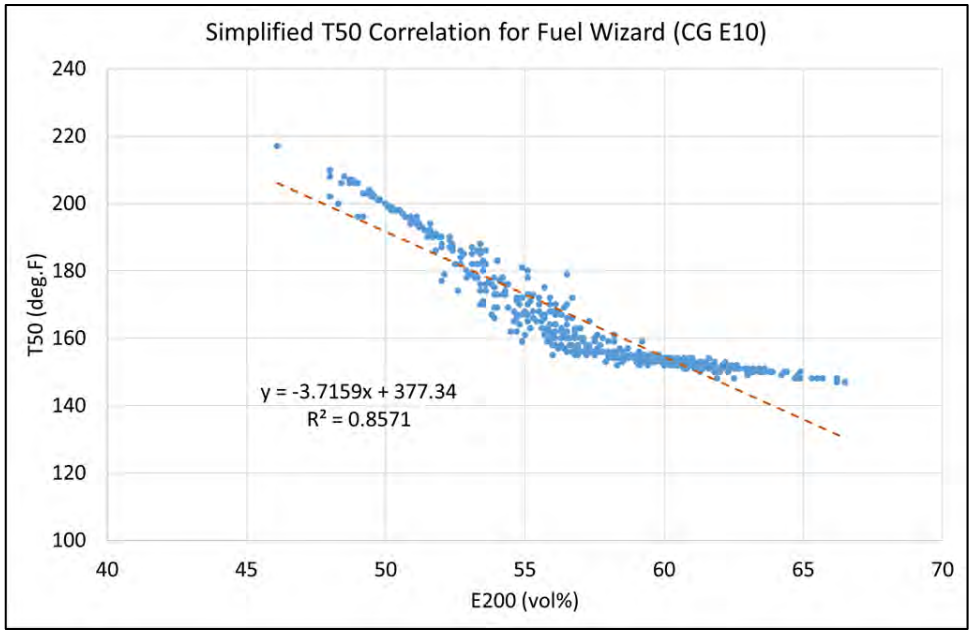

Figure 7-1. Simplified T50 by E200 correlation for use in MOVES Fuel Wizard.

8. References

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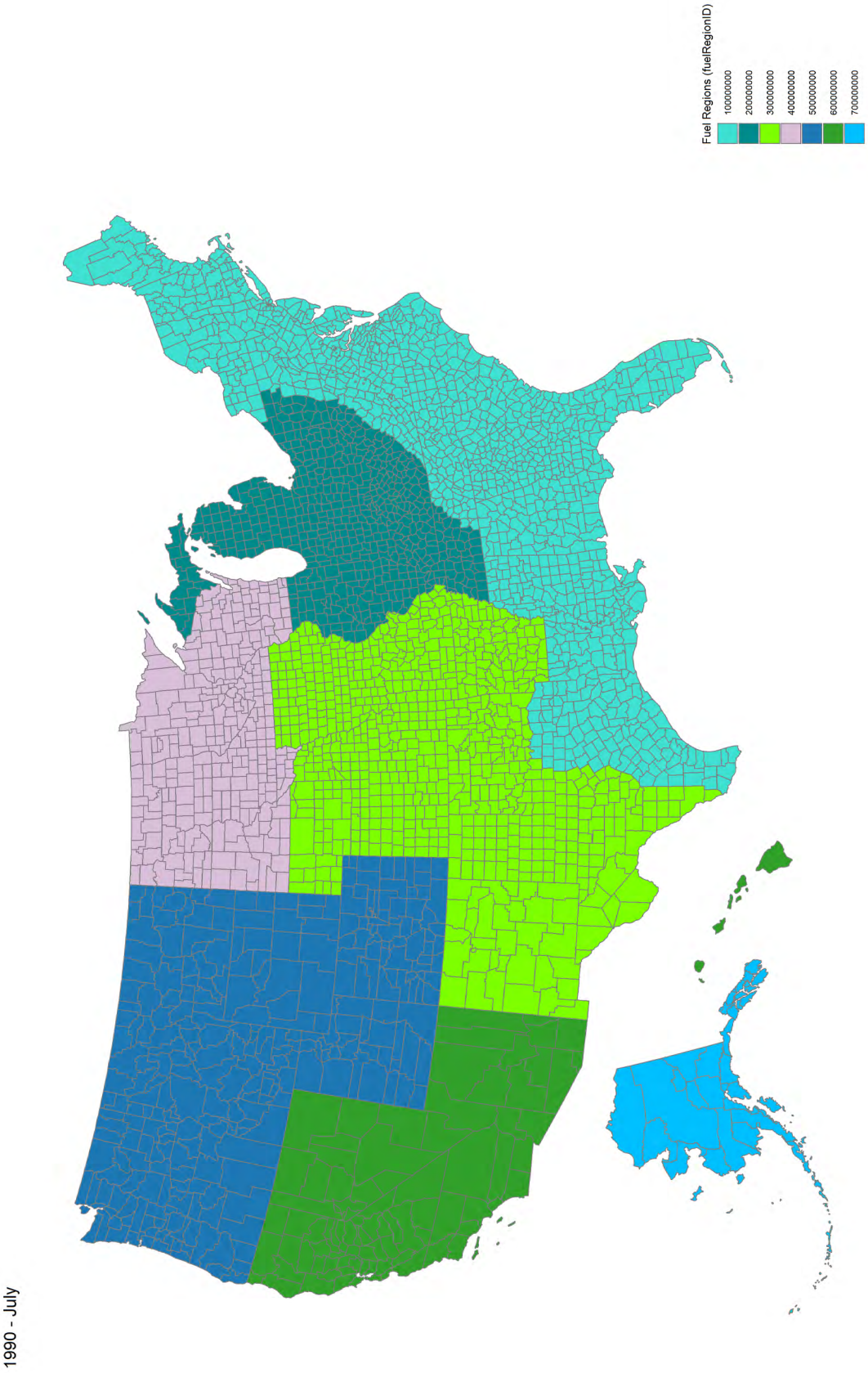
Appendix A: MOVES Fuel Region Maps

This appendix presents maps of summertime MOVES fuel regions by county. Puerto Rico and U.S. Virgin Islands aren't shown but have the same formulation as base region 1 (regionID = 100000000) in all years. While RVPs are generally higher in winter than summer, the MOVES regionID values are identical for both seasons. The map for 2023 is identical to 2022, and thus is omitted. Maps for 2025 and later are identical to 2024.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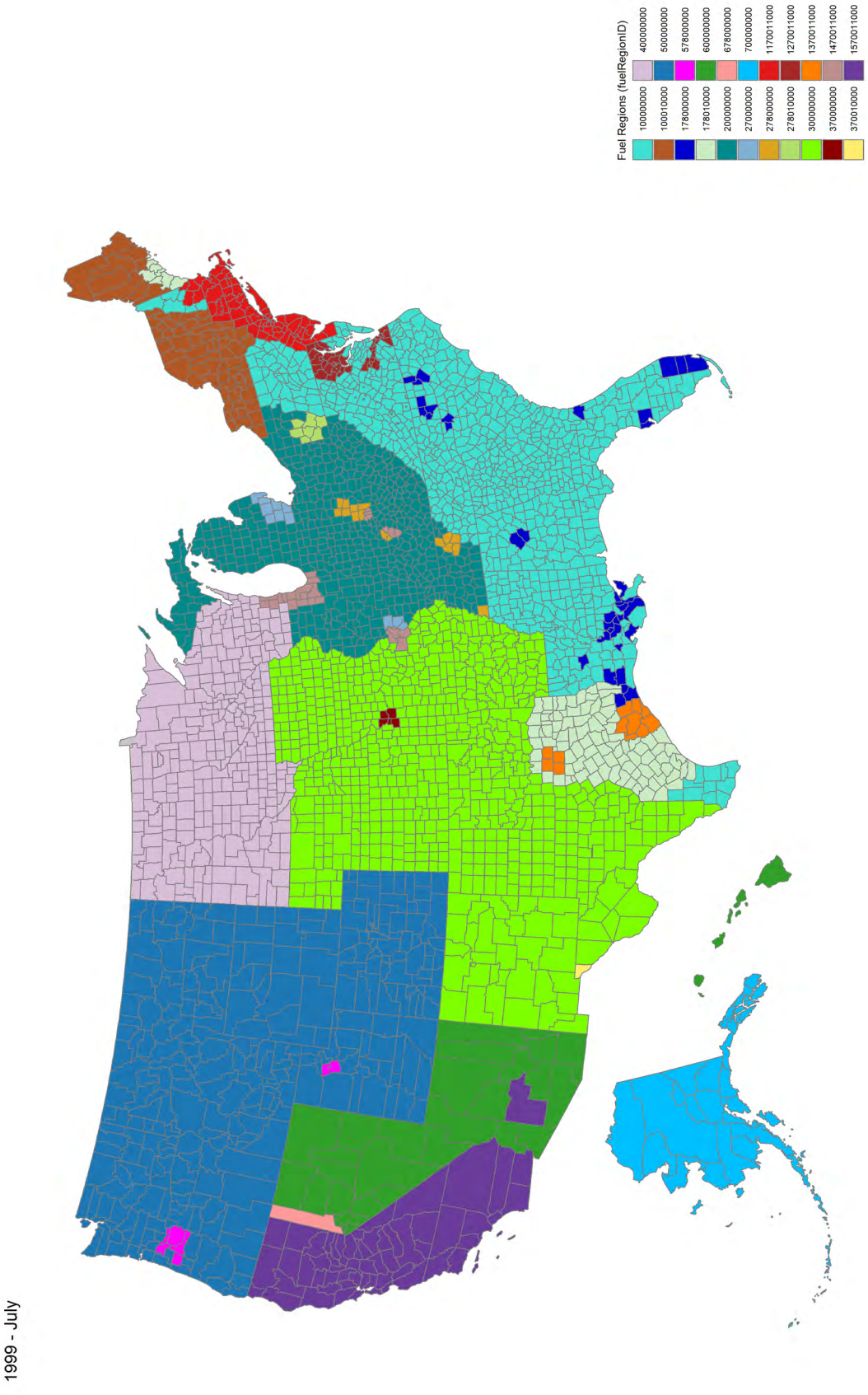
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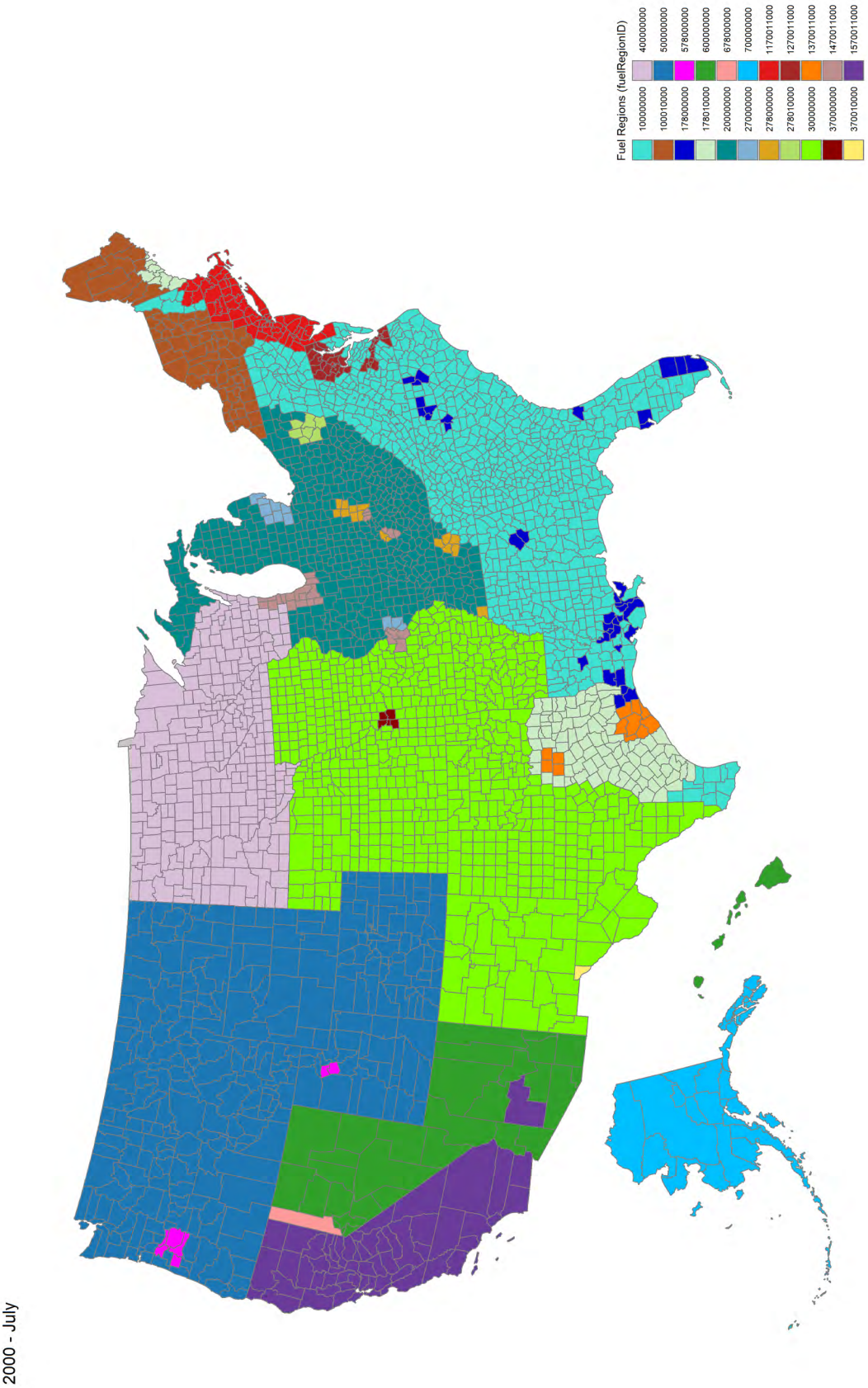
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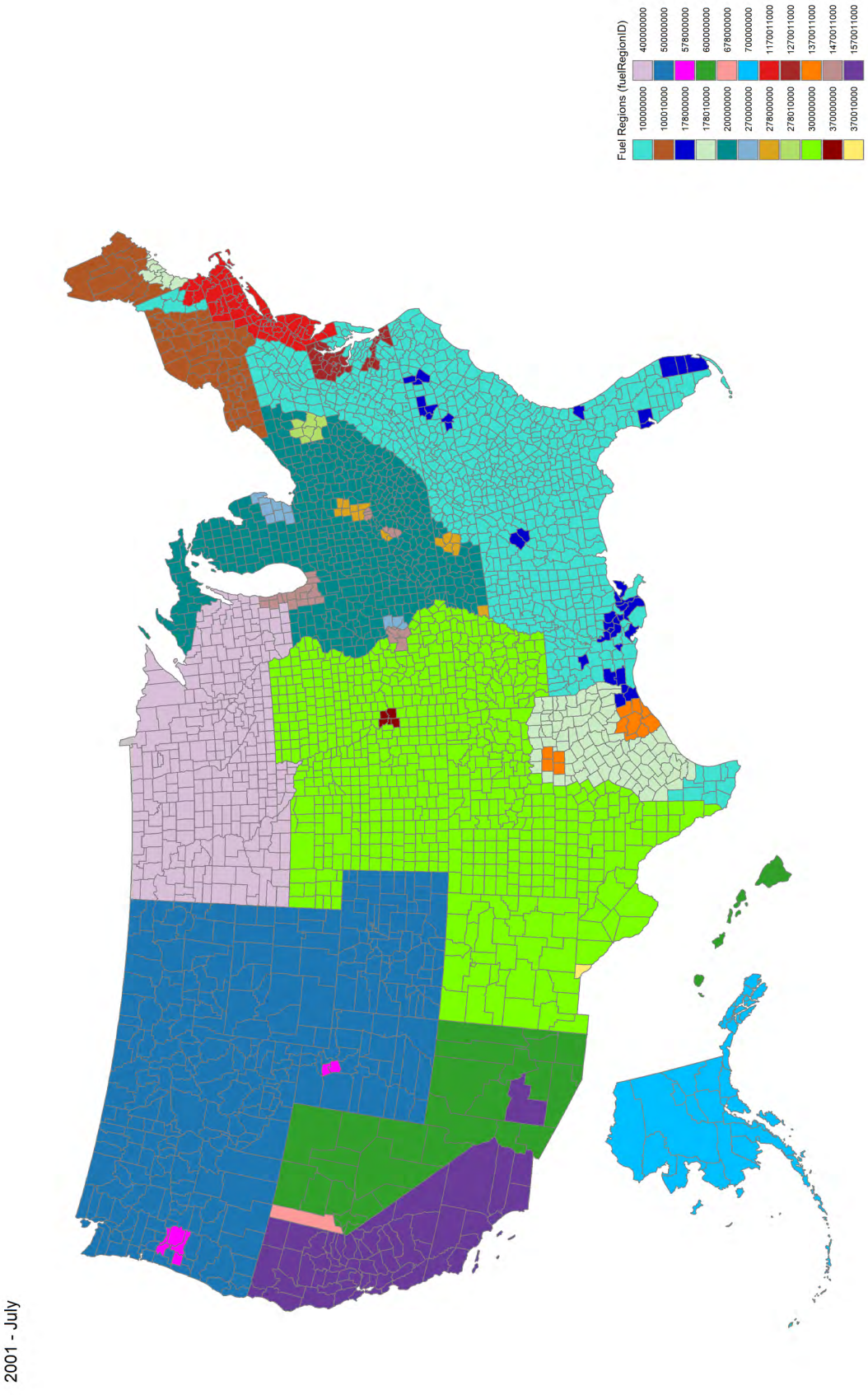
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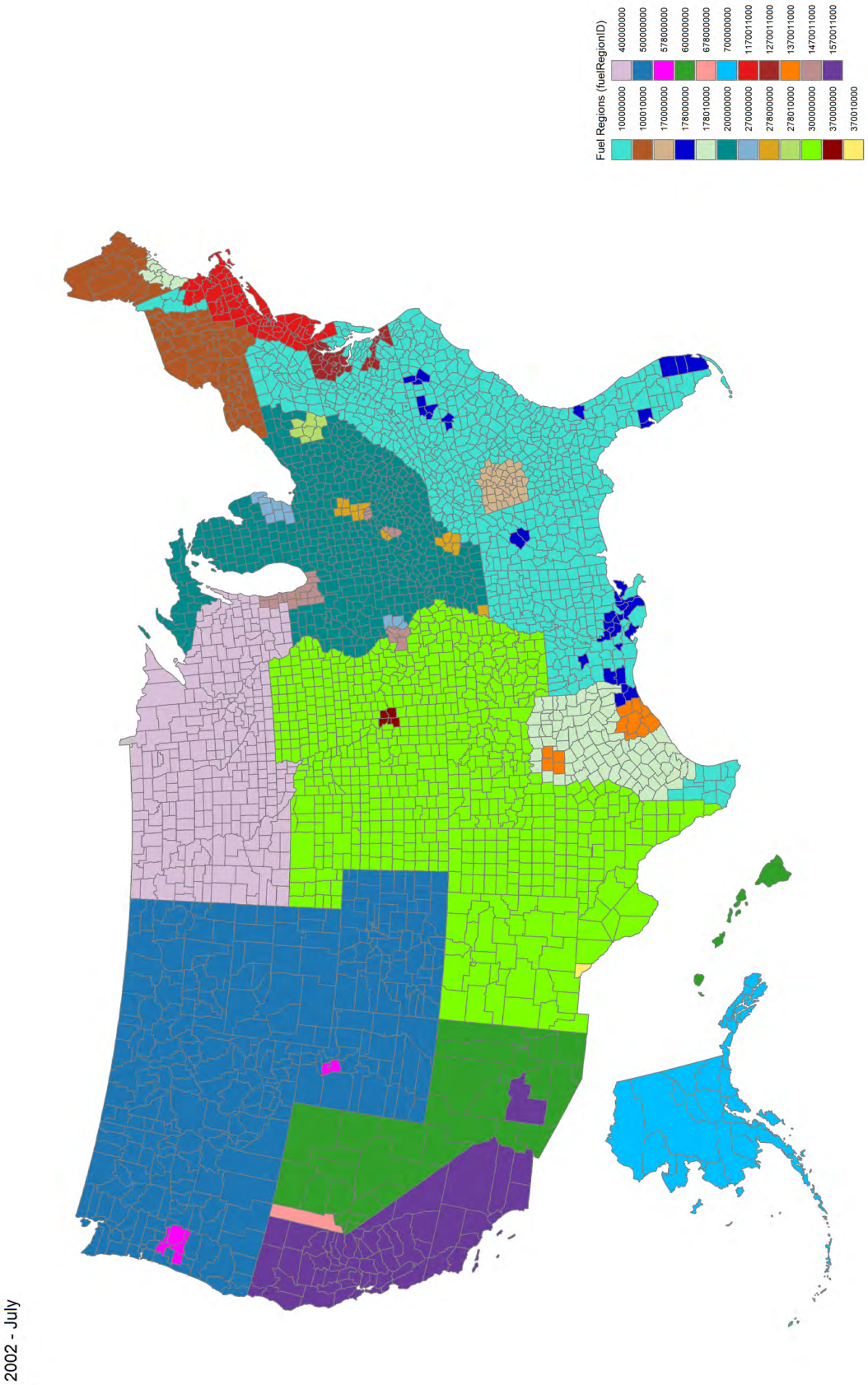
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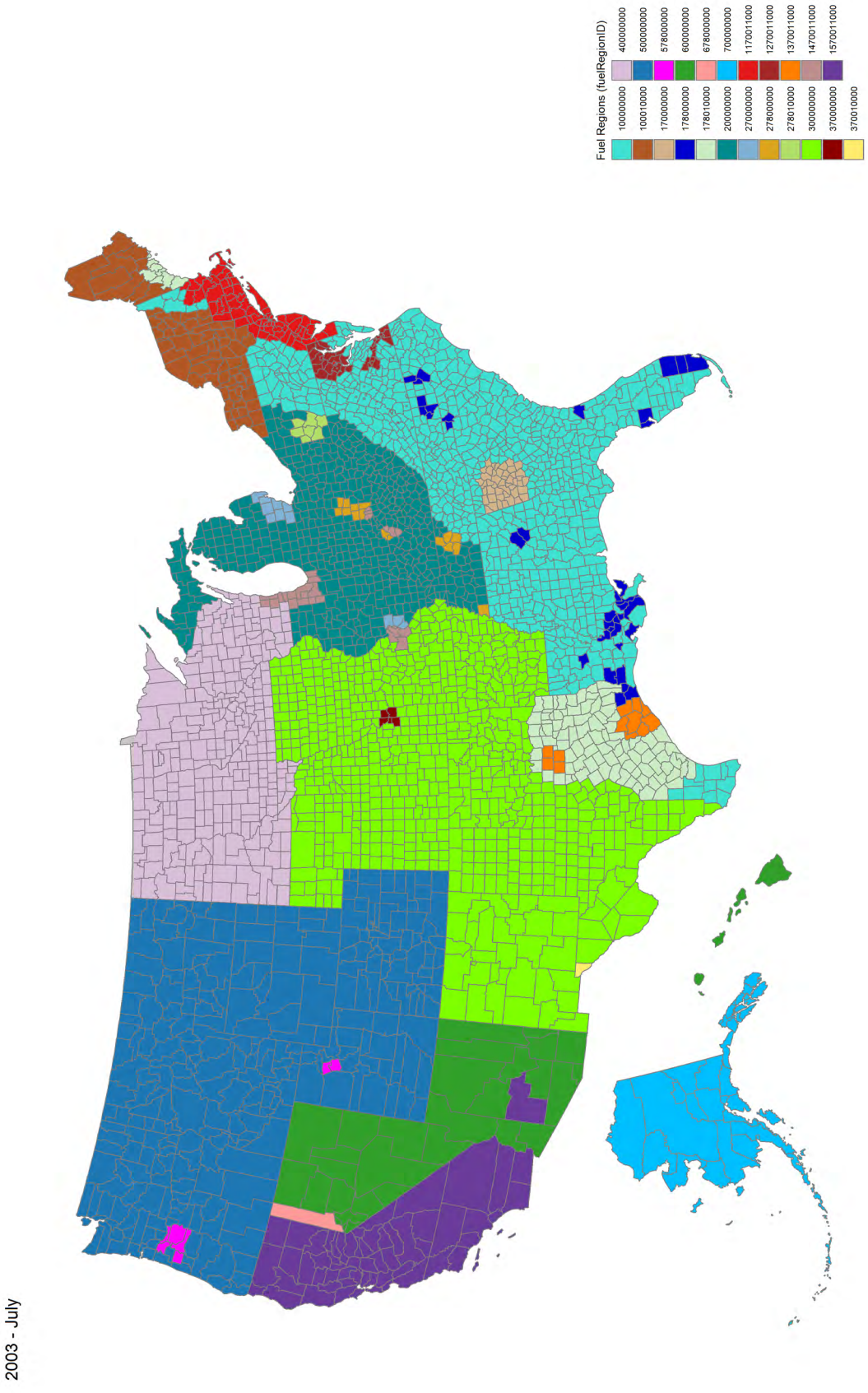
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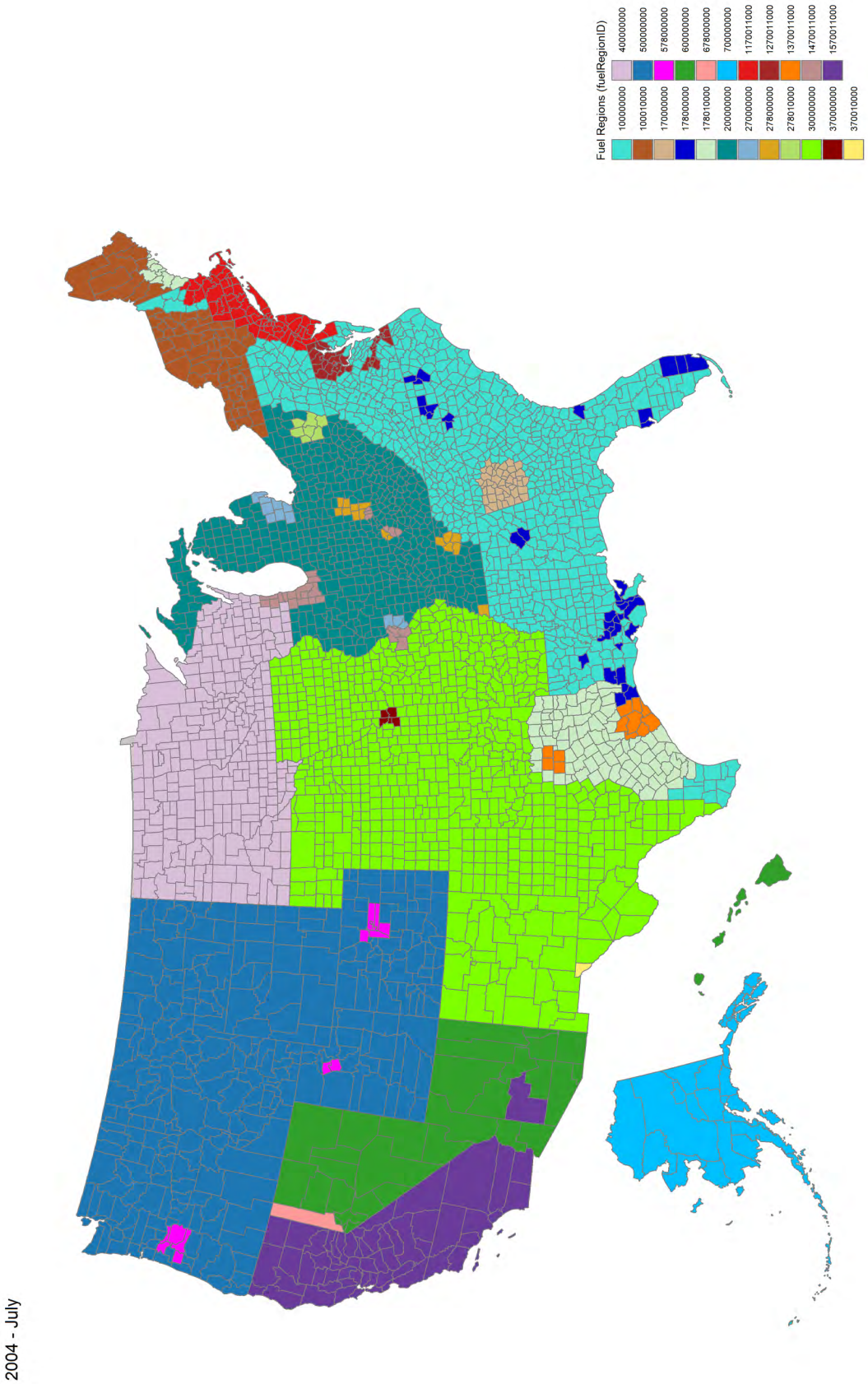
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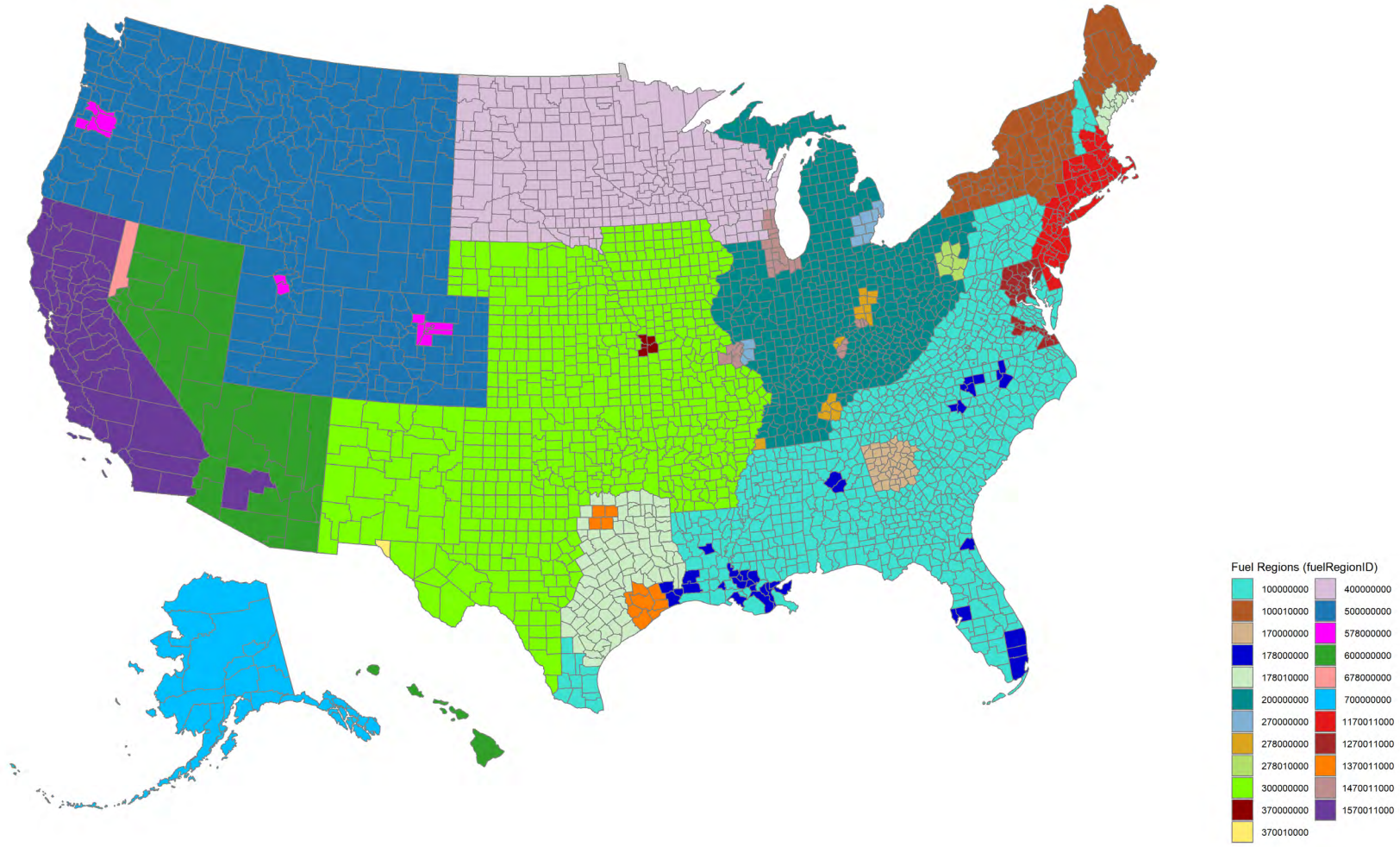
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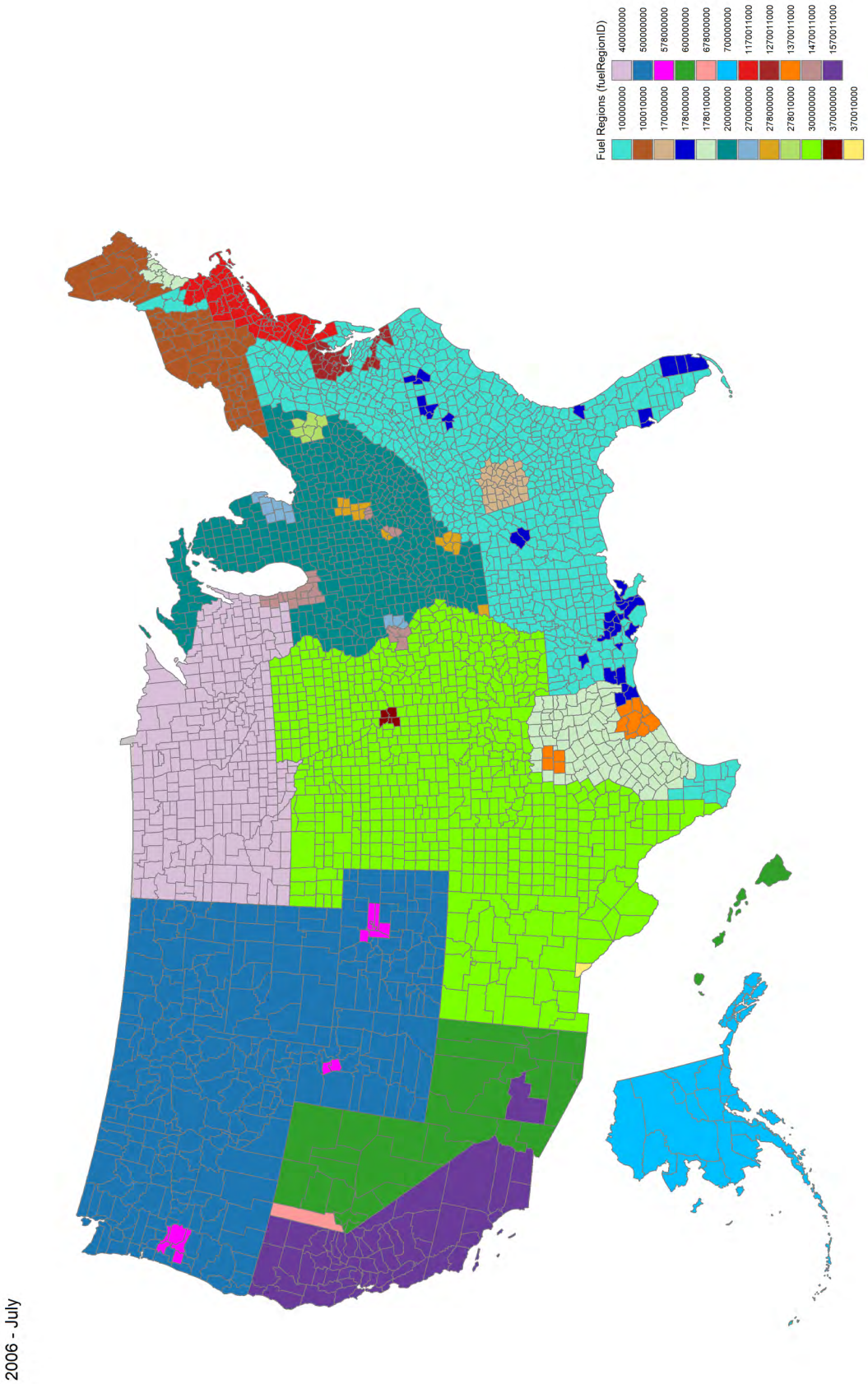
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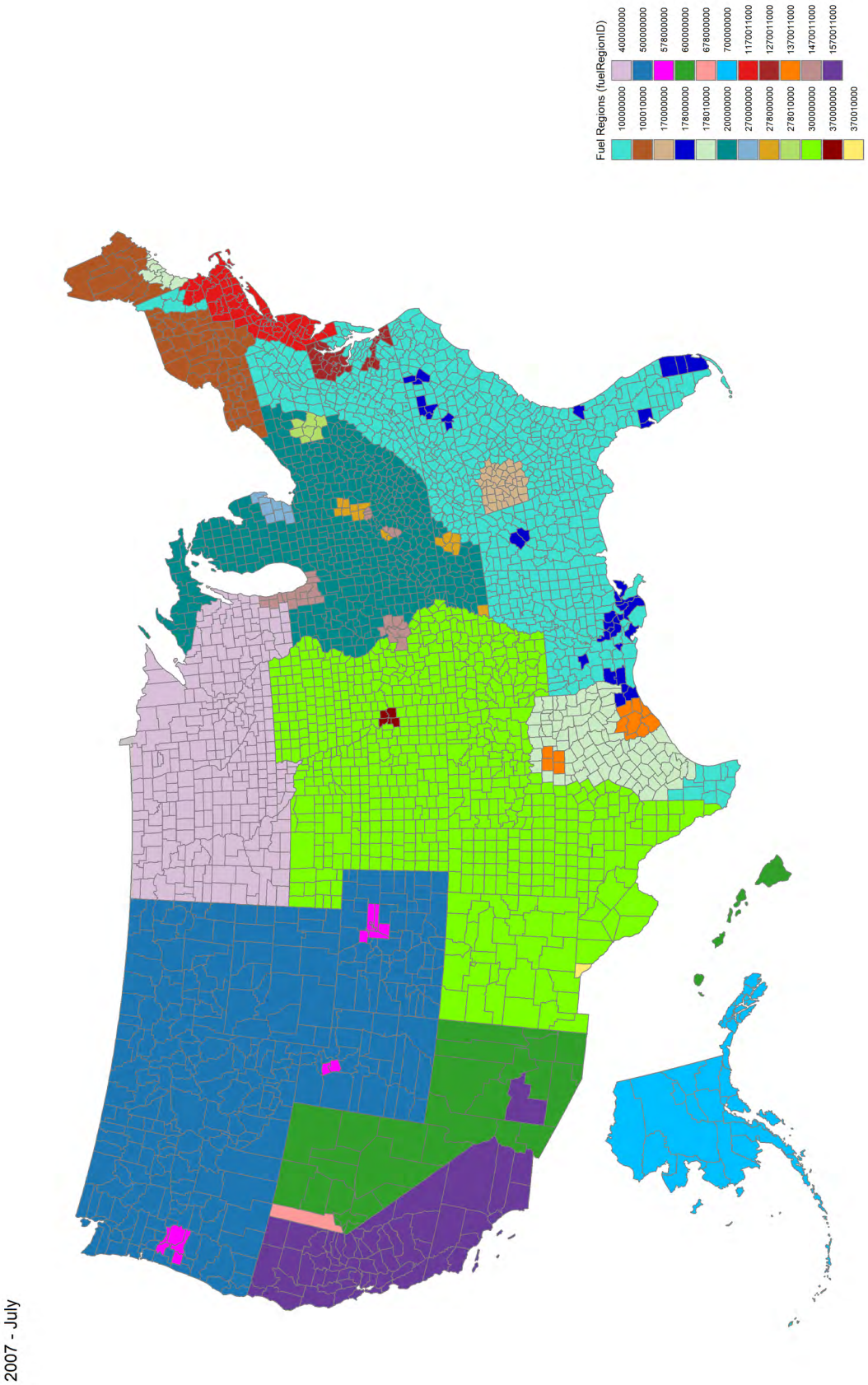
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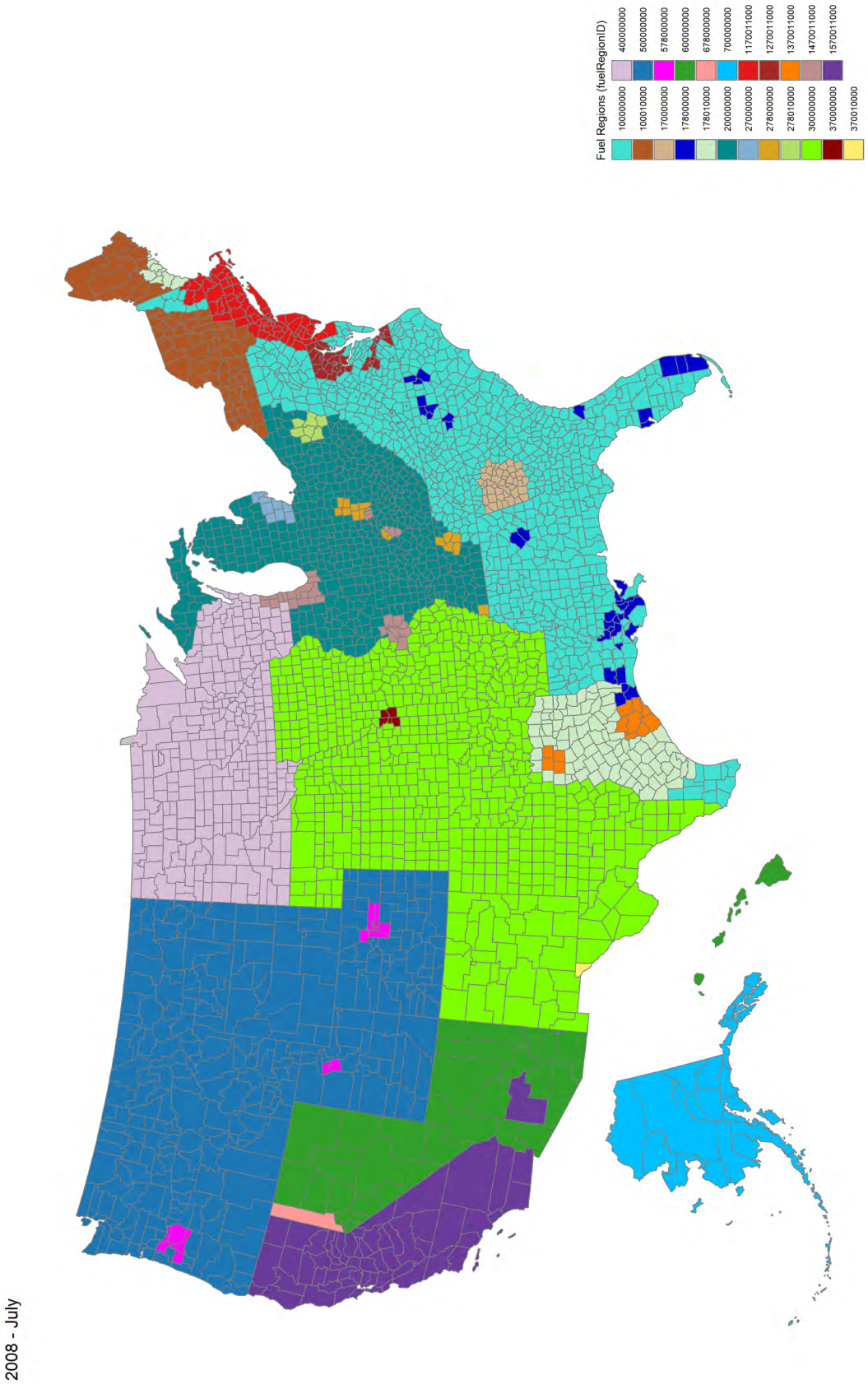
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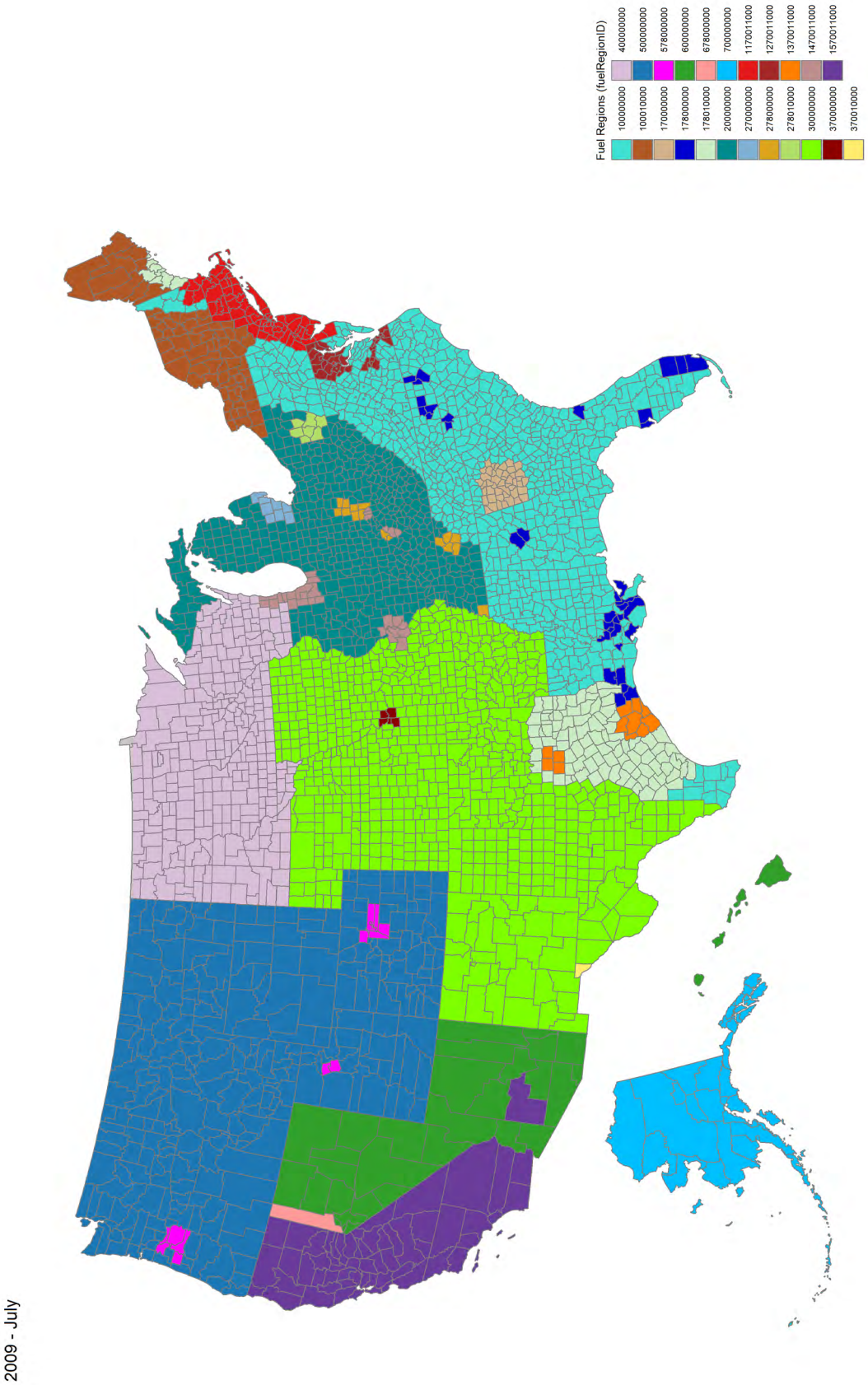
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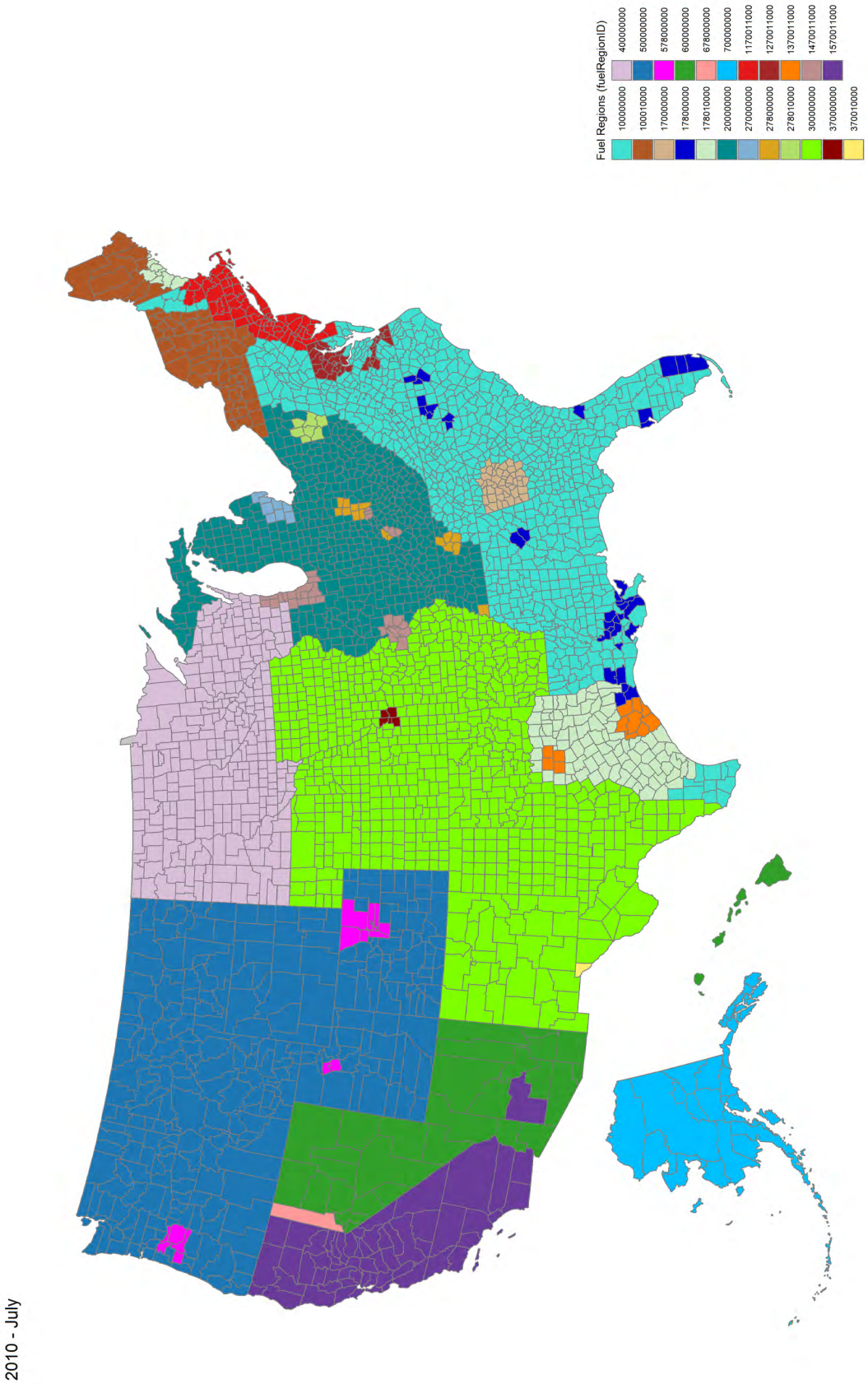
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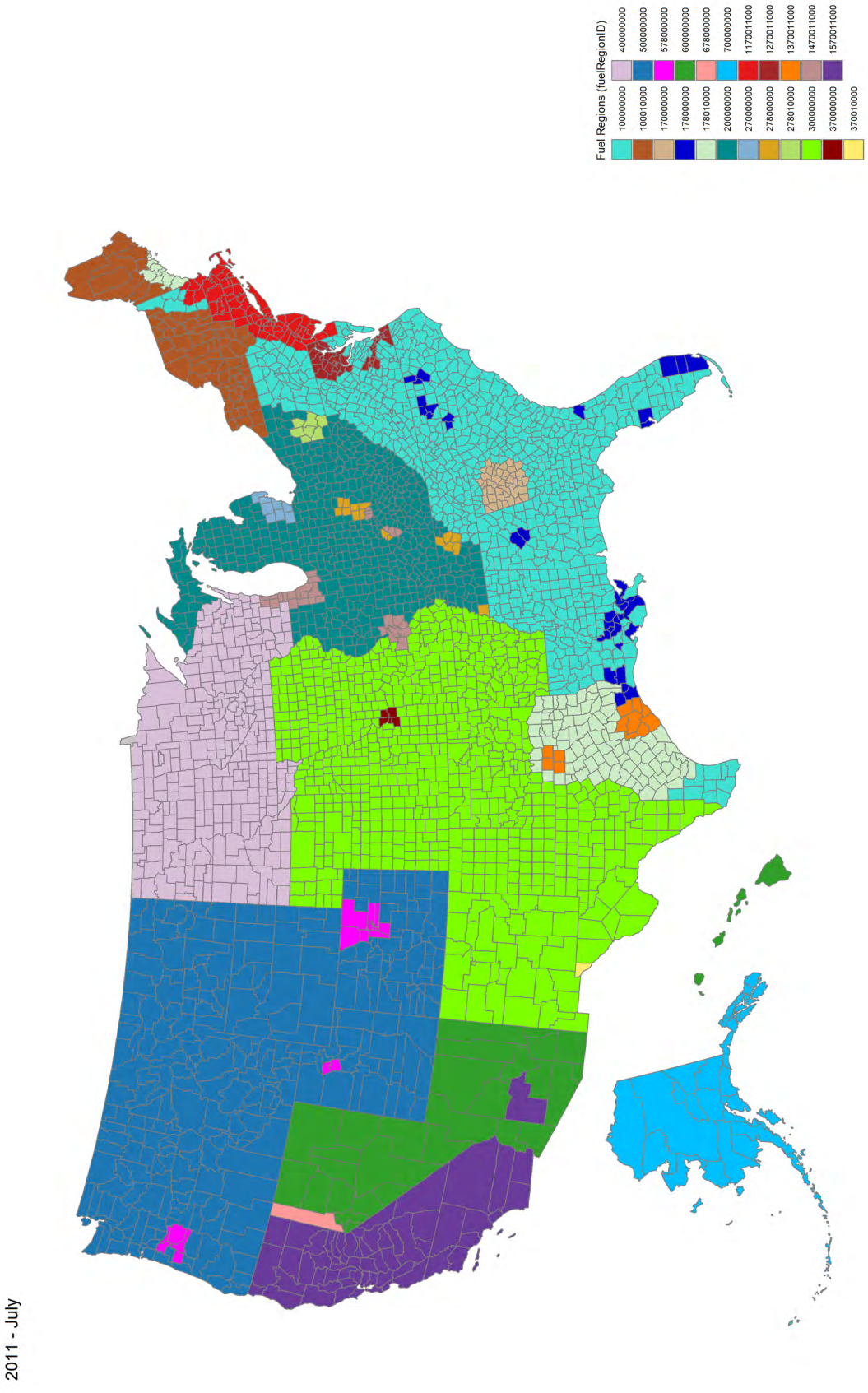
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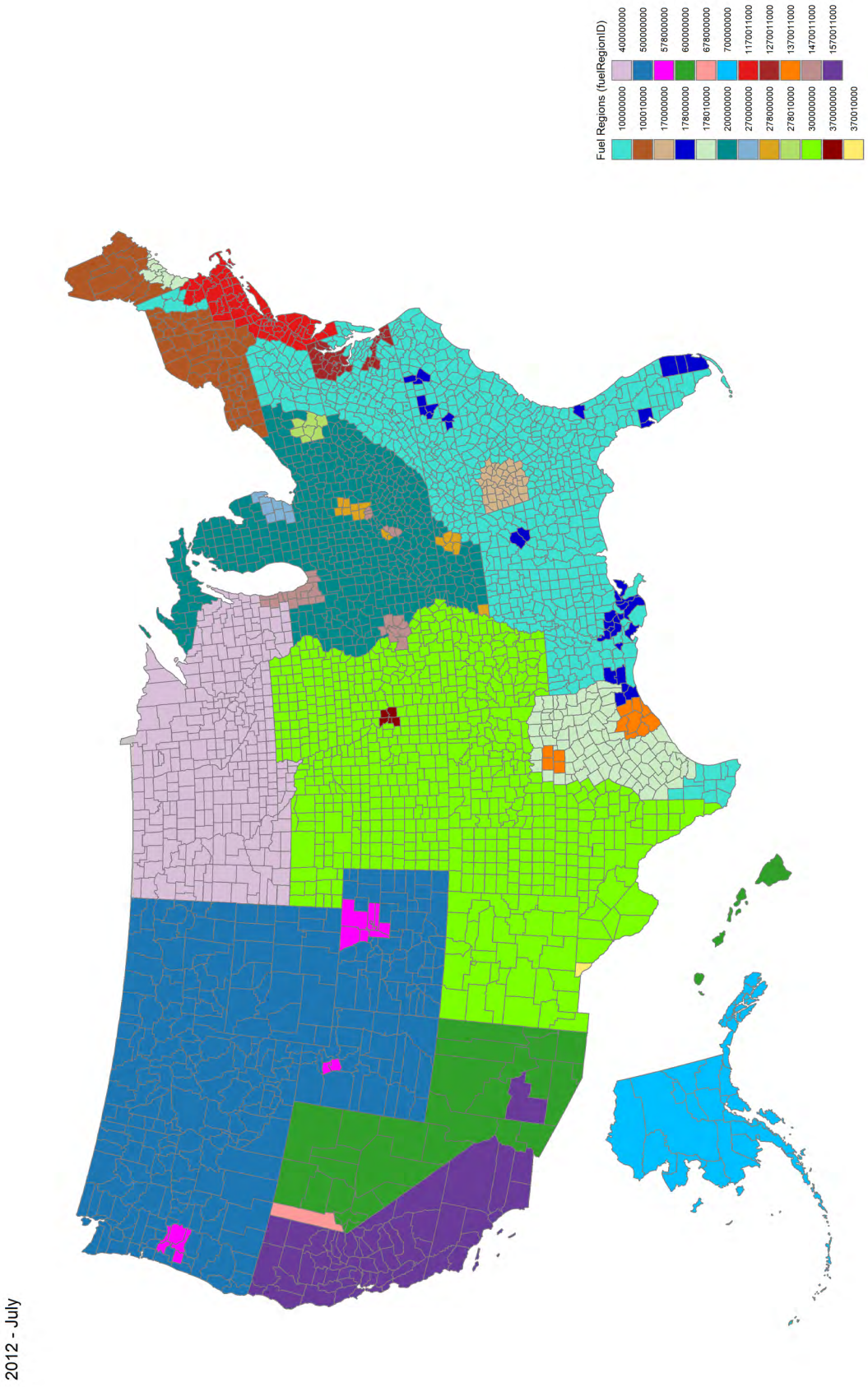
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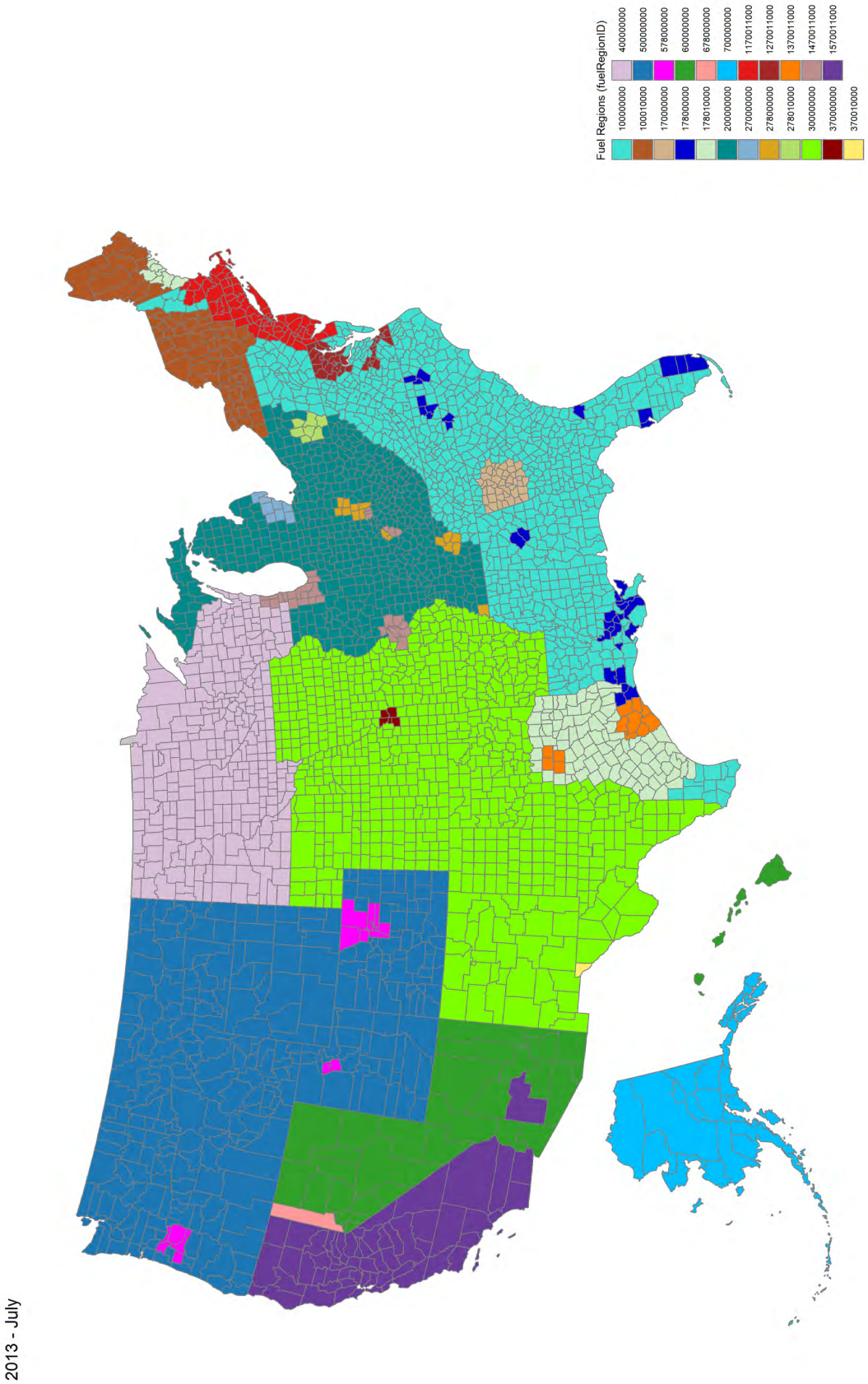
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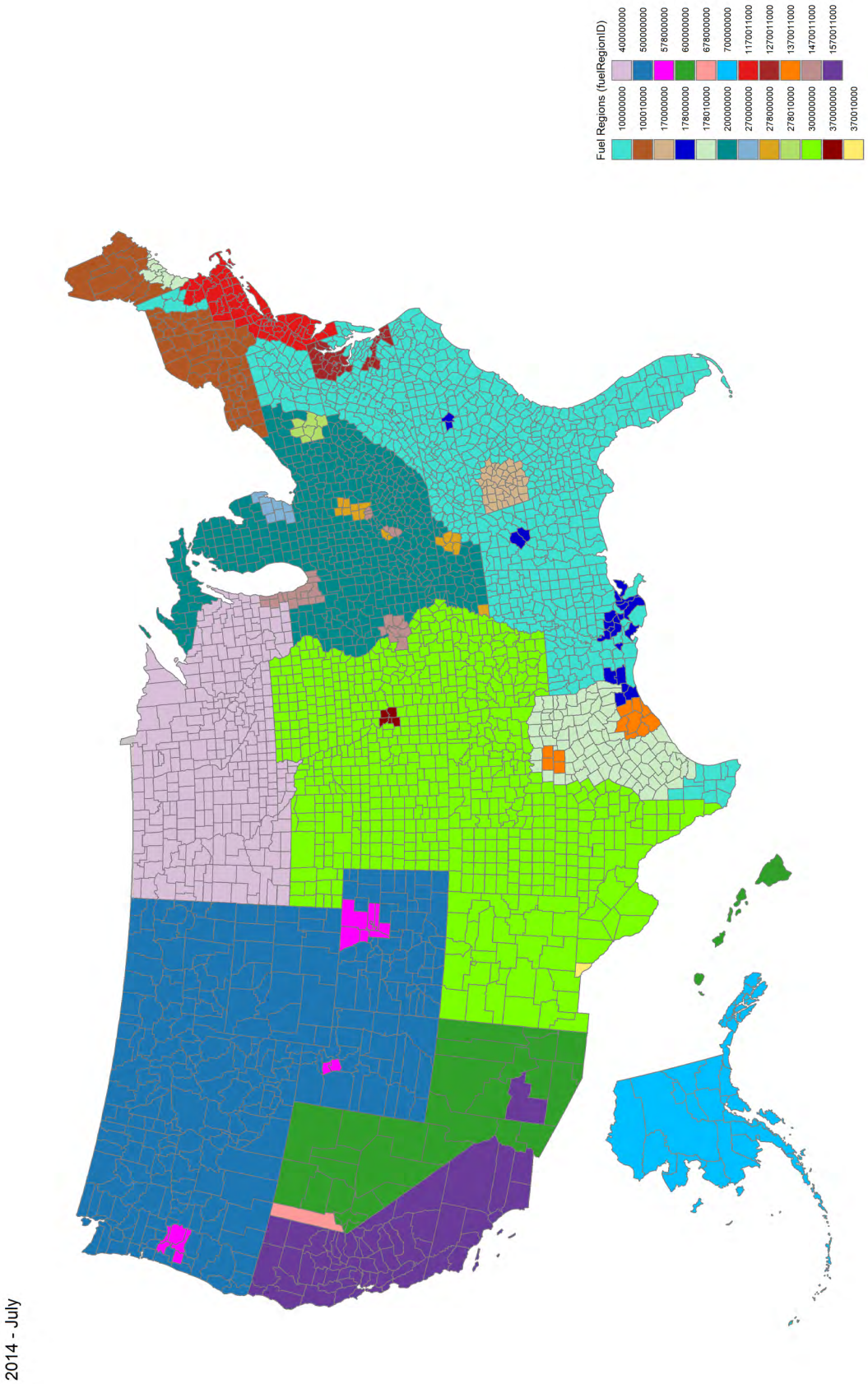
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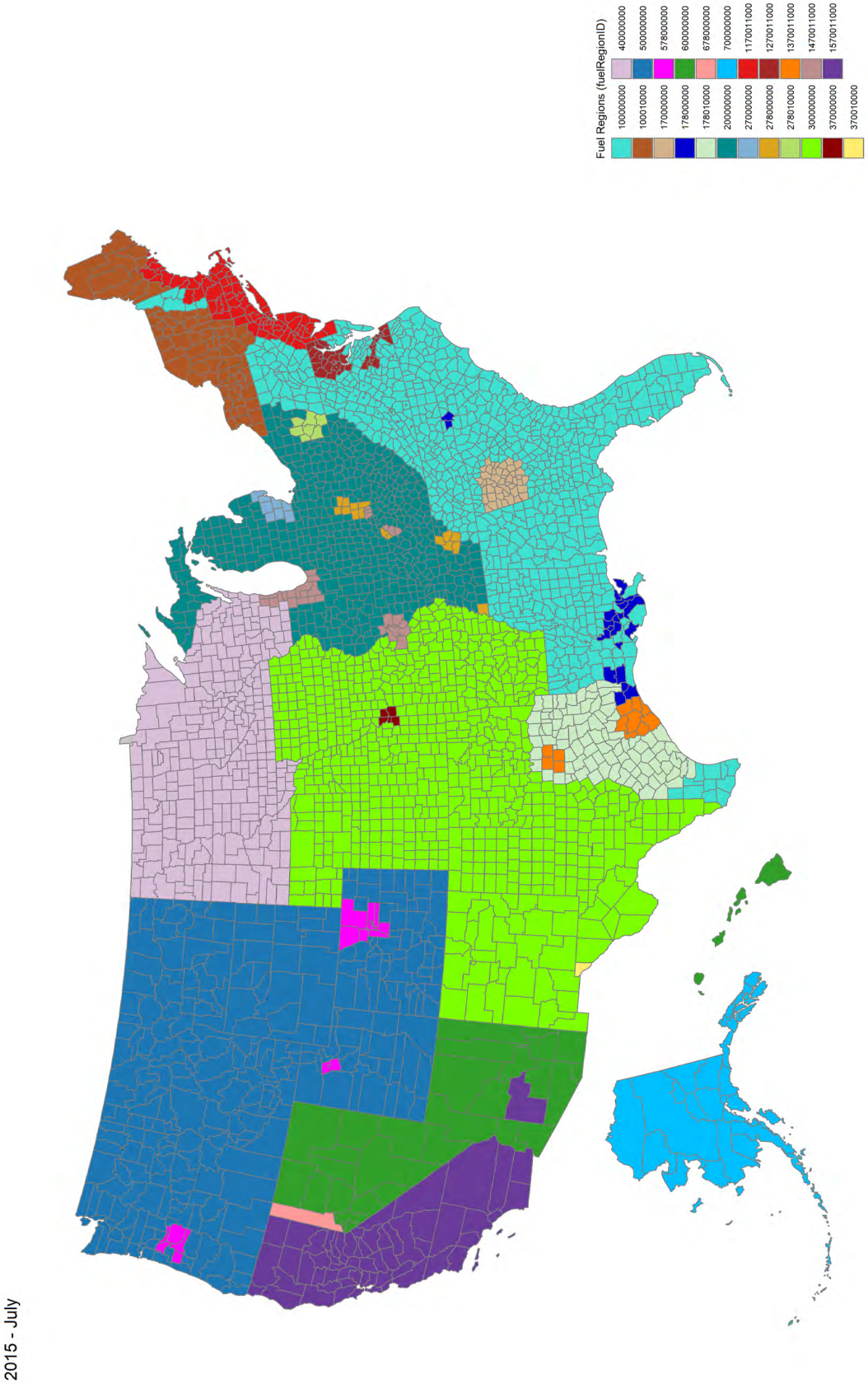
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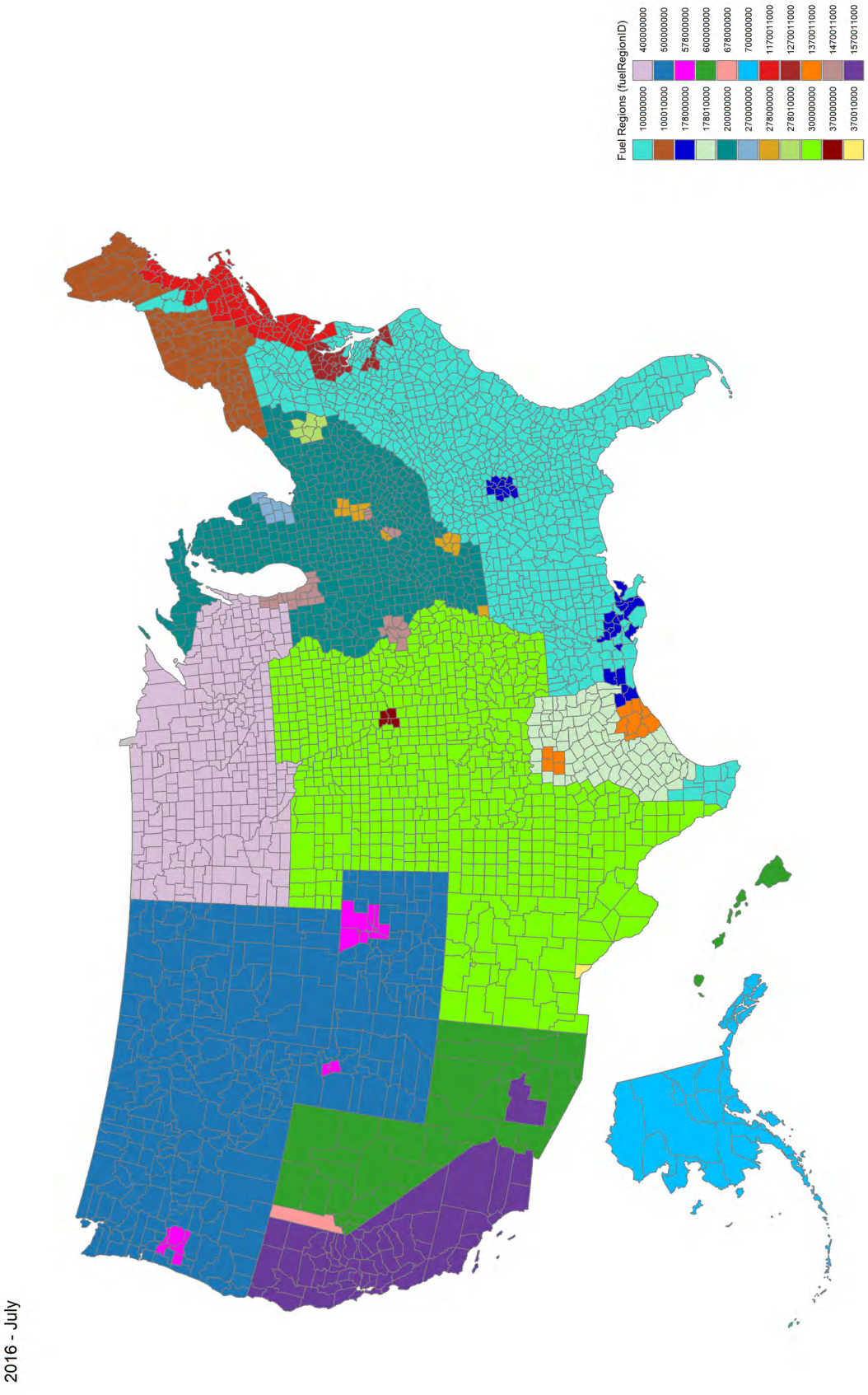
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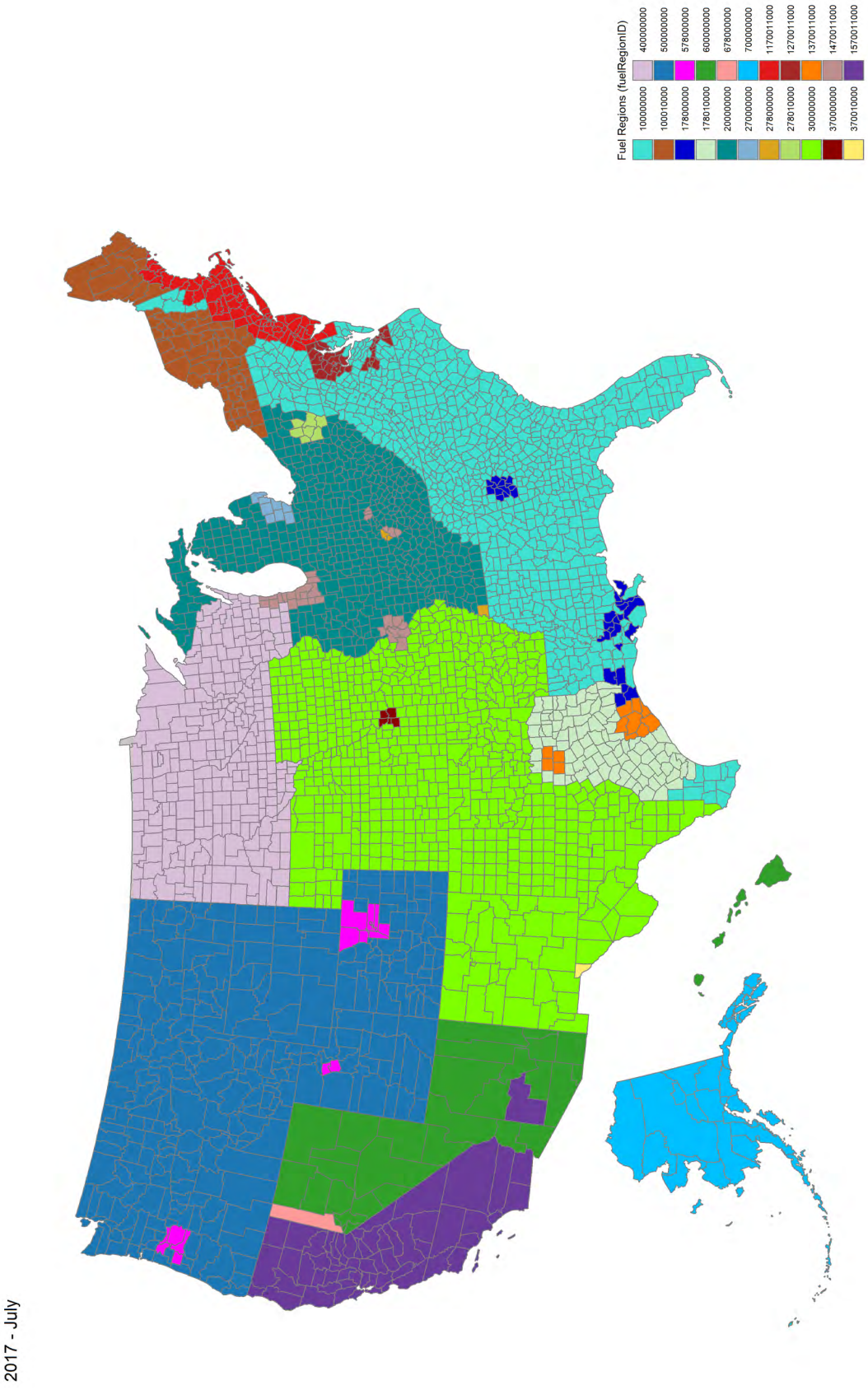
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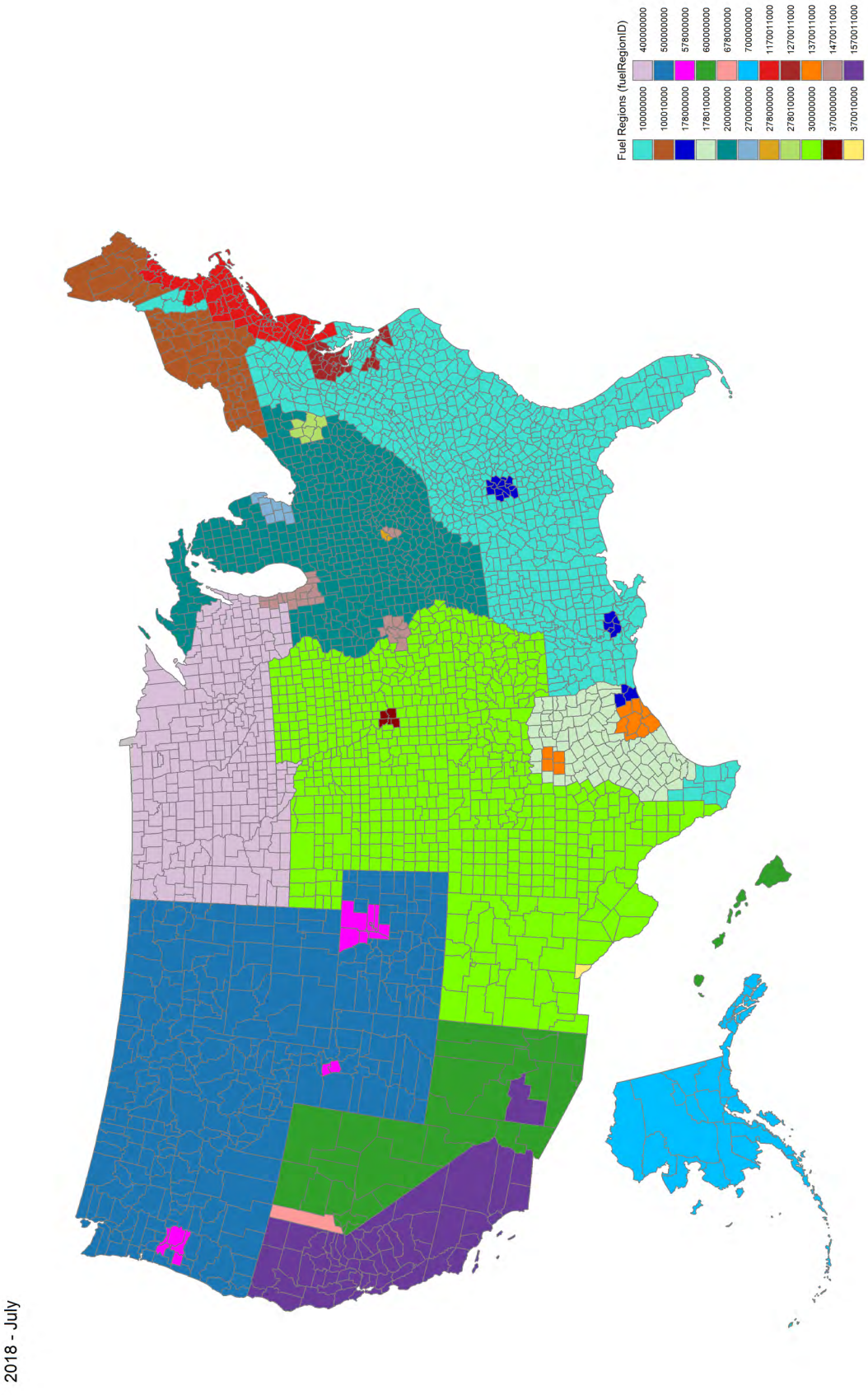
2017 - July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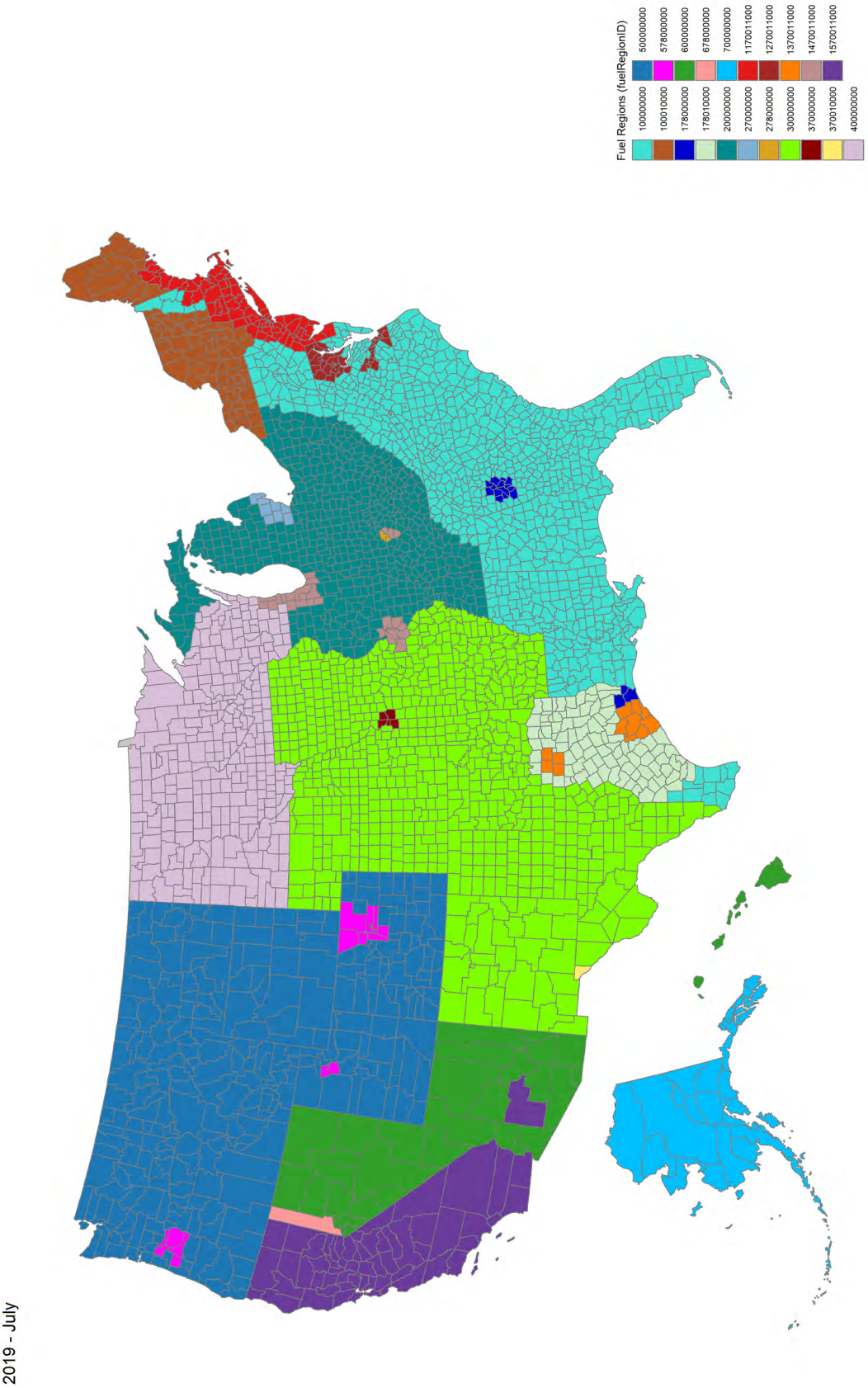
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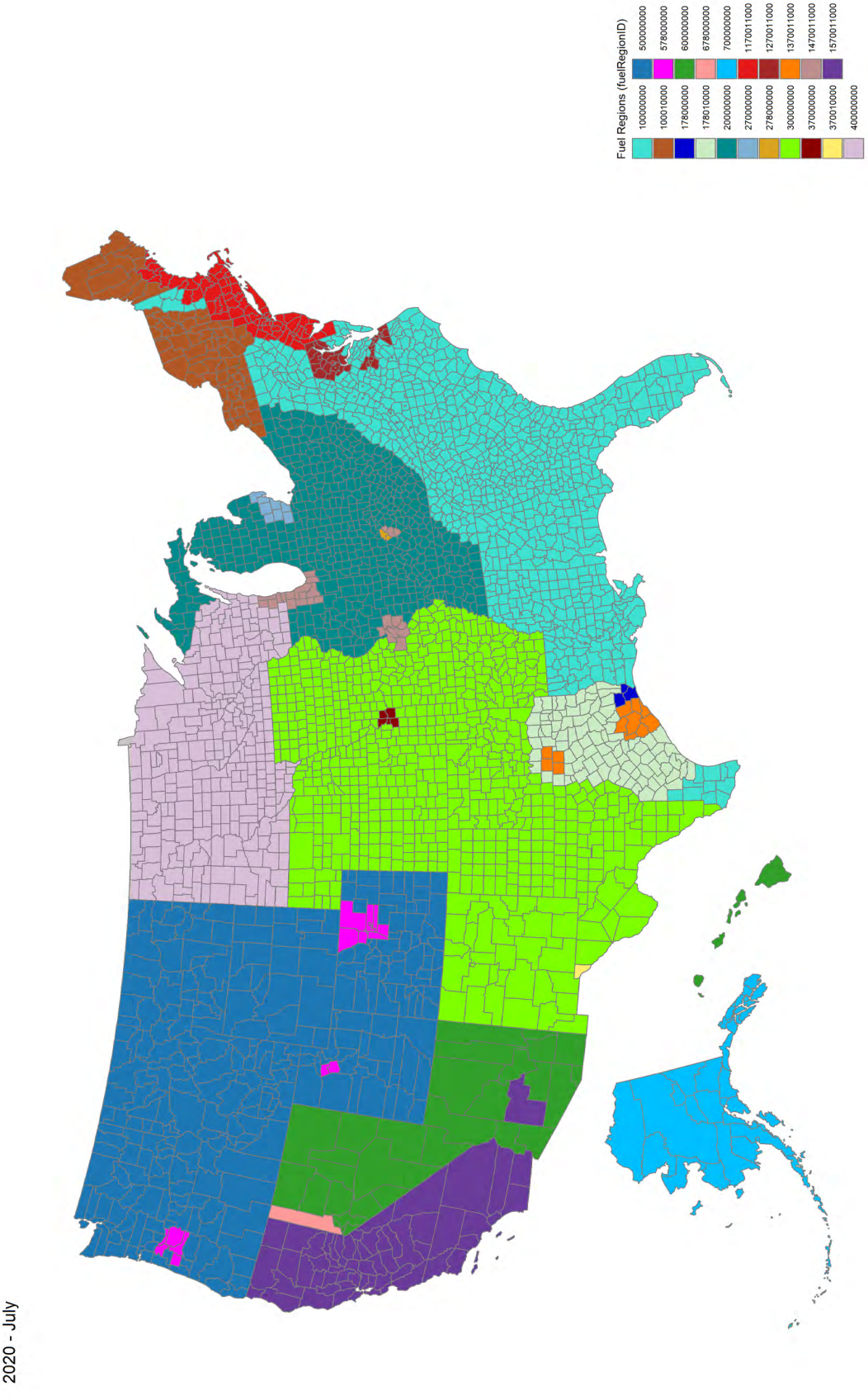
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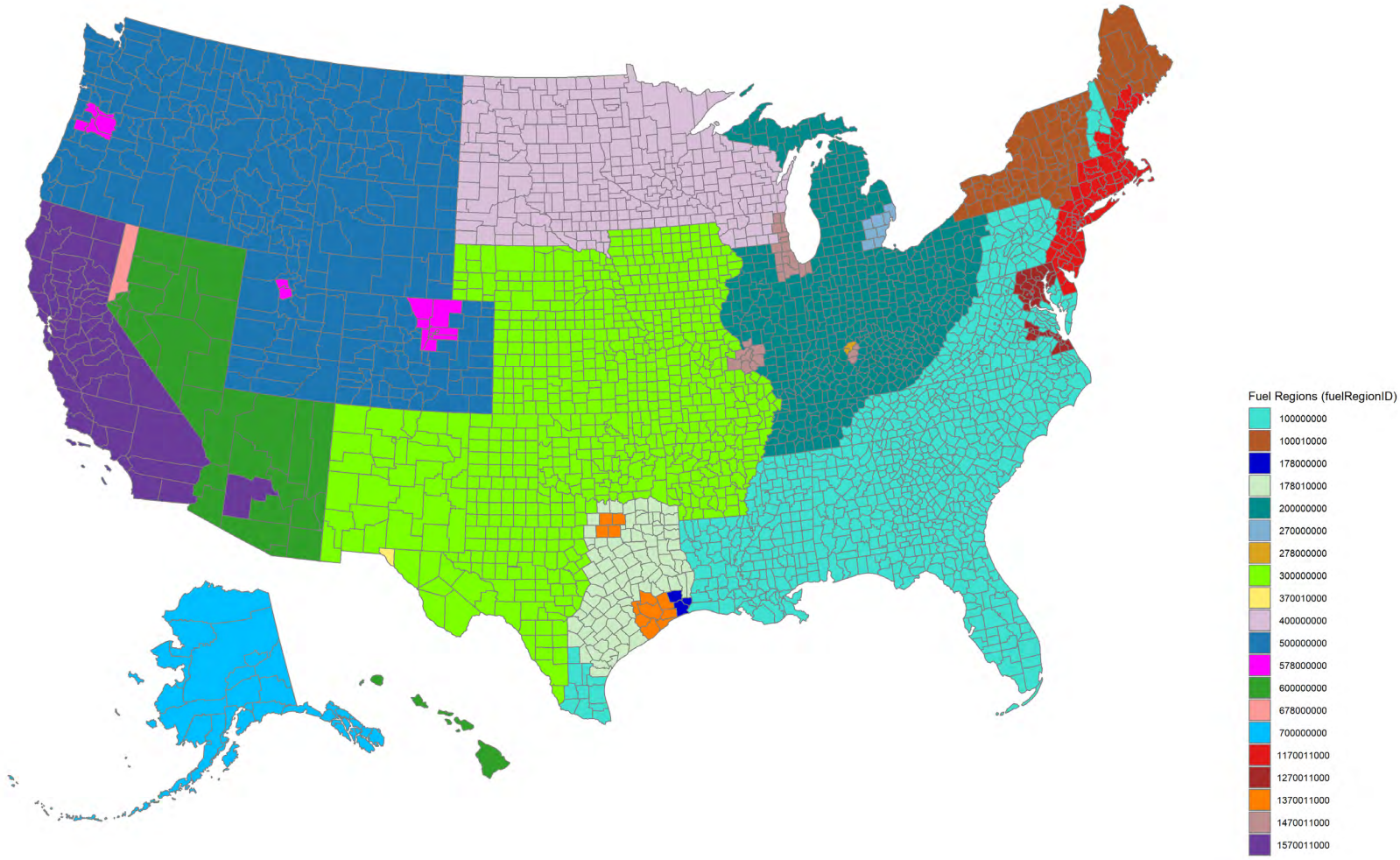
2020 - July

2021 - July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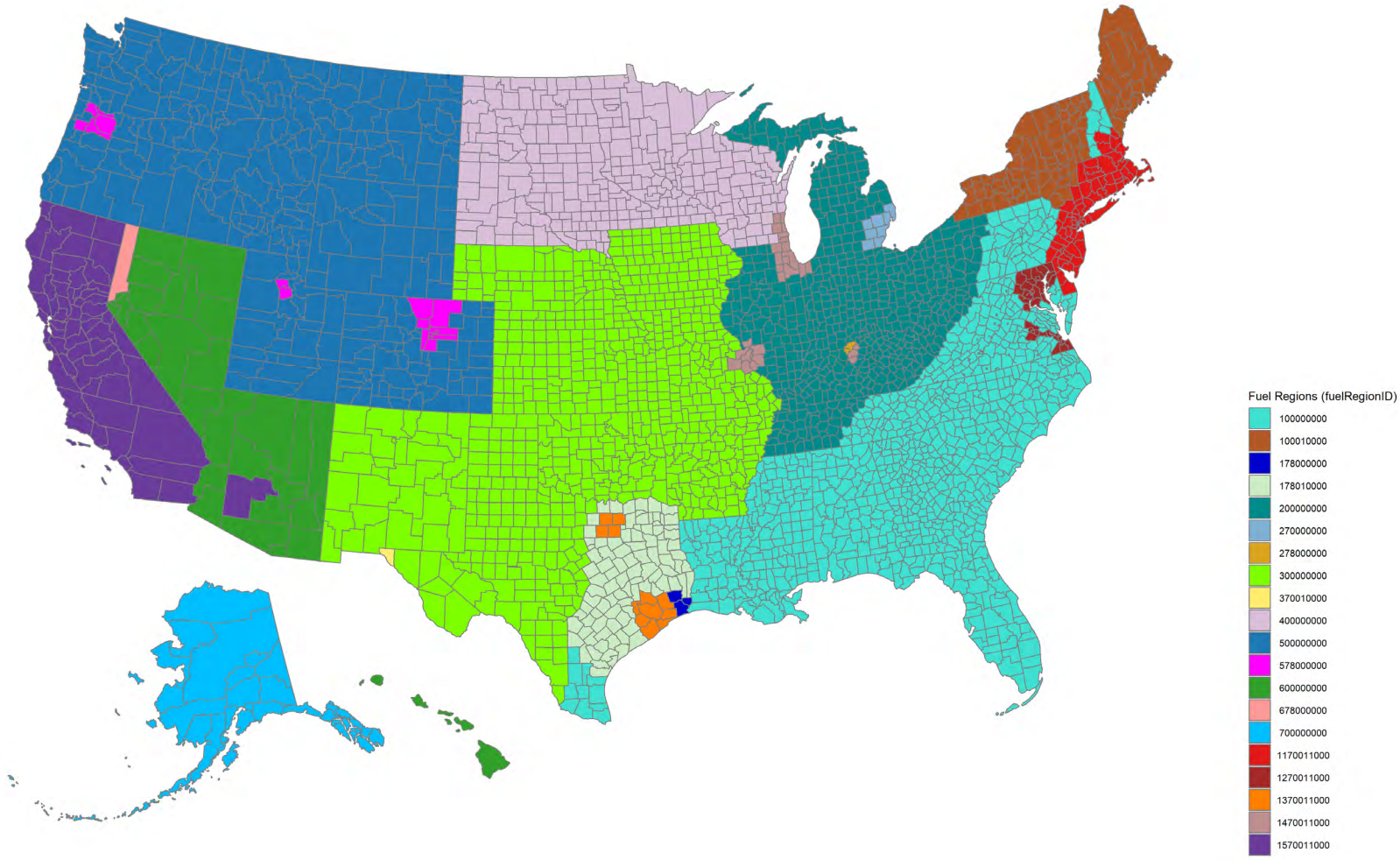
2022 - July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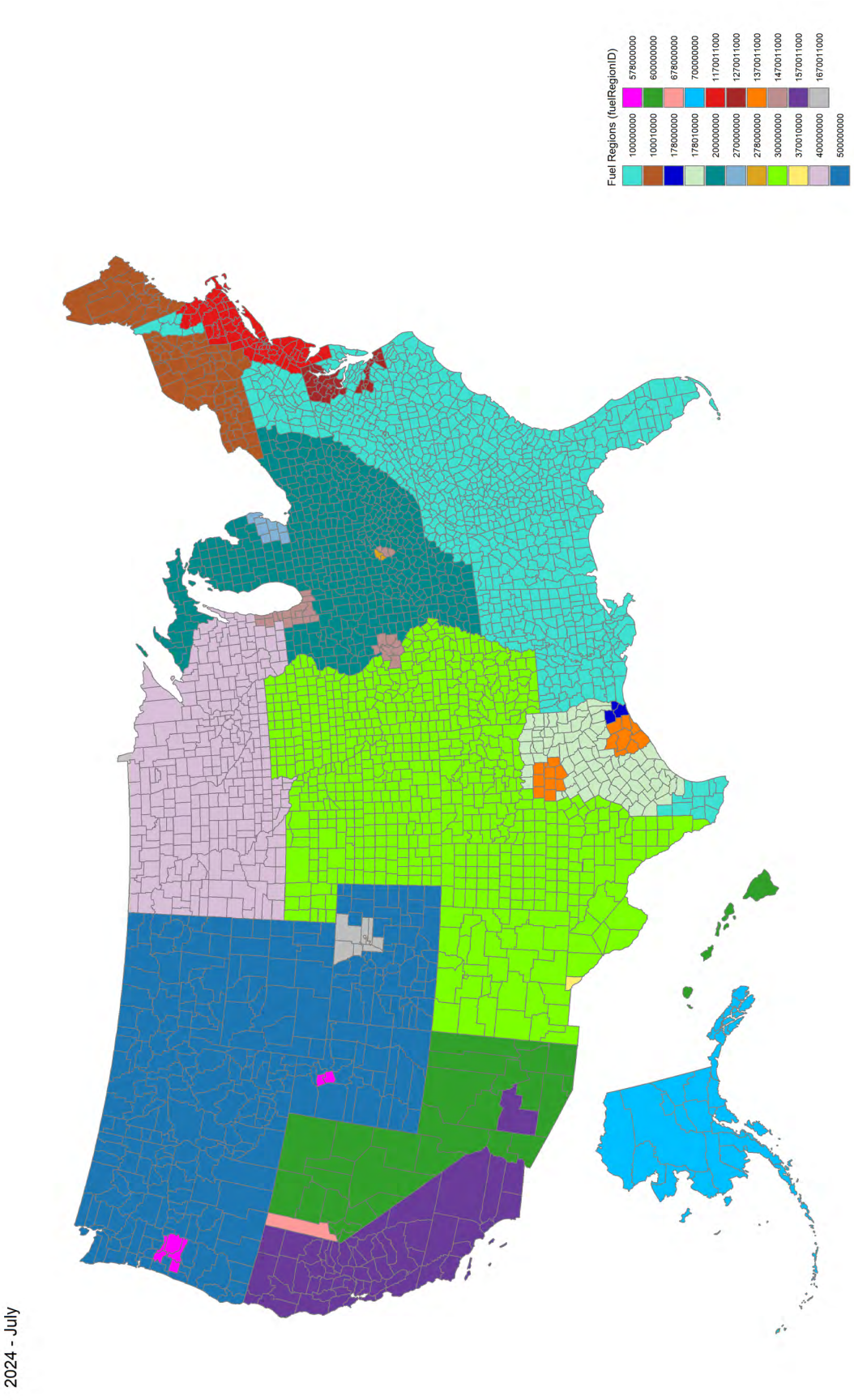
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178000000
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200000000
270000000
278000000
300000000
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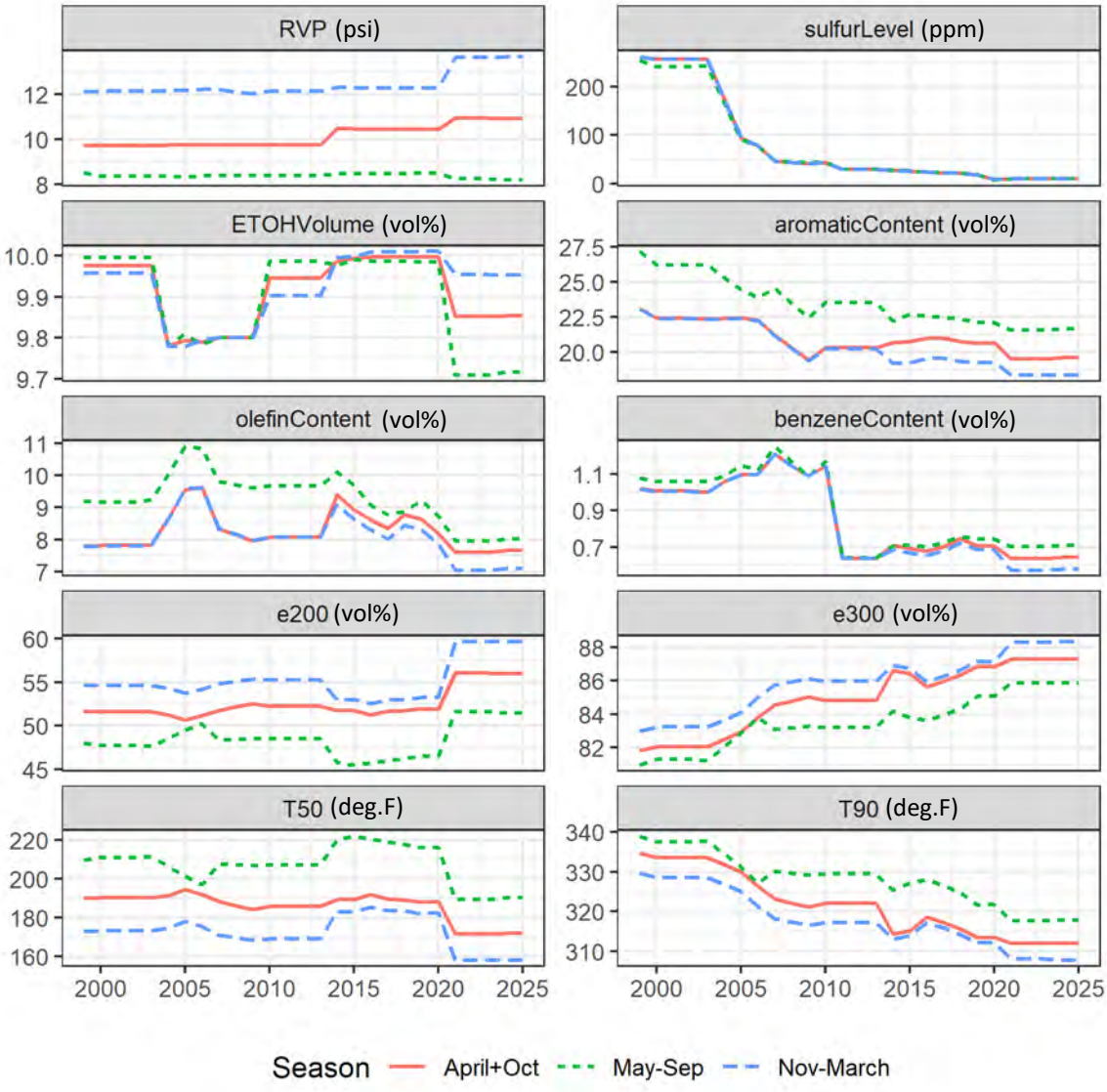
400000000
500000000
2024 - July

Appendix B: Gasoline Formulation Trends in MOVES, 2000-2024

This plot series shows average fuel property values across all E10 fuel formulations by calendar year and season as represented in the default fuel supply (includes all octane grades weighted by sales volume).



Appendix C: Comparison of MOVES5 and MOVES4 Fuel Property Values

The tables below compare MOVES5 to MOVES4 fuel property values by region and season for years 2021 and later. Each number listed here is the MOVES5 value minus the MOVES4 value. The upper table represents summer formulations and the lower winter. Color shading highlights the relative magnitude of changes. For example, many regions now have RVPs lower in summer but higher in winter.

RegionID	RVP	sulfur	ETOH	aromatics	olefins	benzene	e200	e300	T50	T90
100000000	-0.38	5.87	-0.17	-2.95	-1.16	-0.29	7.46	1.14	-40.68	-3.42
100010000	-0.35	5.28	-0.47	-0.93	-2.07	-0.27	4.90	2.69	-28.10	-11.42
178000000	-0.40	4.51	-0.41	-1.95	2.05	-0.45	6.72	2.44	-36.78	-10.54
178010000	-0.40	4.68	-0.26	-1.62	2.23	-0.44	3.70	0.15	-21.90	-1.46
200000000	-0.42	3.30	-0.14	-2.31	-0.16	-0.03	7.90	1.26	-44.43	-3.92
270000000	-0.22	1.88	-0.30	0.69	-0.44	0.18	4.59	-0.41	-25.85	2.54
278000000	-0.40	2.39	-0.39	-2.57	-2.37	0.10	7.42	3.43	-40.80	-14.69
300000000	-0.47	4.19	-0.27	-3.16	-1.74	0.04	7.92	2.19	-43.57	-8.24
370010000	-0.28	-0.99	-0.45	3.43	-3.80	0.37	0.79	1.84	-5.56	-15.27
400000000	-0.37	7.18	-0.46	-6.18	3.67	-0.05	6.12	-1.40	-34.99	7.61
500000000	-0.79	4.36	-0.20	-0.51	-1.28	-0.28	6.90	-1.36	-36.30	6.21
578000000	-0.32	2.49	-0.15	-0.08	-0.79	-0.10	7.97	-1.12	-42.25	4.31
600000000	-0.73	2.41	-0.31	0.07	0.89	0.08	10.01	3.33	-52.80	-14.45
678000000	-0.74	-2.95	-0.34	-1.14	-4.30	-0.19	0.19	-0.14	-0.74	-4.29
700000000	0.83	-1.21	0.00	-0.22	1.03	0.08	7.22	0.29	-15.59	0.85
1170011000	0.29	2.76	-0.26	4.84	-3.64	0.12	4.88	3.44	-16.98	-17.72
1270011000	0.15	6.39	-0.23	1.31	-2.50	-0.08	4.74	1.05	-16.91	-4.02
1370011000	0.15	3.96	-0.23	5.03	-1.39	0.13	2.16	-0.94	-6.99	3.47
1470011000	0.16	2.83	-0.21	4.14	-0.04	0.33	1.68	-2.81	-6.00	13.40
1570011000	-0.07	2.67	0.02	-4.92	3.49	-0.04	-1.11	-0.37	3.95	0.04

RegionID	RVP	sulfur	ETOH	aromatics	olefins	benzene	e200	e300	T50	T90
100000000	1.00	4.22	0.02	-0.23	-0.59	-0.26	7.20	1.99	-26.70	-7.12
100010000	1.00	4.43	-0.16	-1.06	-0.32	-0.22	8.12	3.62	-26.93	-15.25
178000000	1.00	2.03	0.01	2.41	-2.79	-0.36	6.86	0.63	-27.29	-4.17
178010000	1.00	4.82	-0.05	-1.18	2.21	-0.36	5.82	0.92	-24.57	-2.75
200000000	0.70	1.85	0.02	-1.27	-0.71	-0.06	9.43	1.80	-34.61	-6.28
270000000	0.70	-0.32	0.05	-3.51	-0.93	0.06	12.59	0.92	-39.33	0.48
278000000	0.70	-0.02	0.09	1.15	-2.06	-0.35	9.15	1.52	-34.73	-5.78
300000000	2.00	2.07	-0.13	-2.26	-1.50	0.00	9.35	3.24	-39.55	-13.66
370010000	2.00	2.07	-0.13	-2.26	-1.50	0.00	9.35	3.24	-39.55	-13.66
400000000	1.00	2.85	-0.37	-5.20	1.91	-0.07	7.26	-2.64	-22.13	12.71
500000000	2.60	2.31	-0.13	-1.60	-1.46	-0.24	9.74	0.52	-41.22	-2.01
578000000	3.60	1.62	-0.06	-1.68	-0.72	-0.21	10.04	0.65	-41.91	-3.11
600000000	3.00	2.53	-0.04	0.51	1.74	0.07	11.08	4.38	-56.33	-18.83
678000000	1.89	-3.61	-0.05	0.21	-2.01	-0.19	-0.54	-0.77	-0.16	2.06
700000000	0.00	-1.73	0.00	0.02	-0.30	-0.04	5.42	-0.25	-12.17	4.05
1170011000	0.30	3.24	-0.02	0.35	-3.09	0.00	2.66	1.99	-1.40	-8.71
1270011000	0.30	3.20	0.05	-0.59	-4.36	-0.11	2.21	0.23	-0.82	0.51
1370011000	1.70	4.42	0.01	1.79	-1.12	0.08	2.37	-0.23	0.72	3.23
1470011000	1.00	2.41	0.10	0.47	0.01	0.08	1.30	-0.46	-0.41	5.74
1570011000	-0.35	2.18	-0.29	-2.32	3.31	-0.05	-5.71	-0.71	9.39	2.33

The tables below show the percent change in fuel property values for MOVES5 relative to MOVES4 by region and season for years 2021 and later. The upper table represents summer formulations and the lower winter. Color shading highlights the relative magnitude of the changes above and below zero percent.

RegionID	RVP	sulfur	ETOH	aromatics	olefins	benzene	e200	e300	T50	T90
100000000	-4%	82%	-2%	-13%	-12%	-29%	15%	1%	-20%	-1%
100010000	-4%	74%	-5%	-4%	-22%	-28%	10%	3%	-13%	-4%
178000000	-5%	63%	-4%	-8%	22%	-46%	14%	3%	-17%	-3%
178010000	-5%	66%	-3%	-7%	24%	-45%	8%	0%	-10%	0%
200000000	-4%	46%	-1%	-10%	-2%	-4%	16%	1%	-21%	-1%
270000000	-3%	26%	-3%	3%	-6%	25%	10%	0%	-12%	1%
278000000	-5%	33%	-4%	-11%	-32%	15%	16%	4%	-18%	-4%
300000000	-5%	59%	-3%	-14%	-17%	5%	17%	3%	-21%	-3%
370010000	-4%	-14%	-4%	15%	-38%	53%	2%	2%	-3%	-5%
400000000	-4%	100%	-5%	-24%	66%	-6%	12%	-2%	-17%	2%
500000000	-8%	61%	-2%	-2%	-14%	-29%	14%	-2%	-17%	2%
578000000	-4%	35%	-2%	0%	-8%	-11%	17%	-1%	-19%	1%
600000000	-7%	34%	-3%	0%	11%	12%	23%	4%	-22%	-4%
678000000	-8%	-41%	-3%	-4%	-51%	-28%	0%	0%	0%	-1%
700000000	7%	-20%	0%	-1%	94%	6%	13%	0%	-8%	0%
1170011000	4%	38%	-3%	27%	-29%	20%	11%	4%	-8%	-5%
1270011000	2%	87%	-2%	7%	-20%	-14%	11%	1%	-8%	-1%
1370011000	2%	54%	-2%	36%	-12%	28%	5%	-1%	-3%	1%
1470011000	2%	41%	-2%	25%	-1%	67%	4%	-3%	-3%	4%
1570011000	-1%	89%	0%	-21%	145%	-7%	-2%	0%	2%	0%

RegionID	RVP	sulfur	ETOH	aromatics	olefins	benzene	e200	e300	T50	T90
100000000	8%	52%	0%	-1%	-7%	-30%	14%	2%	-15%	-2%
100010000	8%	55%	-2%	-6%	-4%	-26%	15%	4%	-15%	-5%
178000000	8%	25%	0%	13%	-35%	-42%	13%	1%	-15%	-1%
178010000	8%	59%	0%	-6%	28%	-42%	11%	1%	-13%	-1%
200000000	5%	23%	0%	-7%	-11%	-9%	18%	2%	-18%	-2%
270000000	5%	-4%	1%	-18%	-14%	10%	24%	1%	-21%	0%
278000000	5%	0%	1%	6%	-31%	-56%	18%	2%	-18%	-2%
300000000	17%	25%	-1%	-11%	-16%	0%	19%	4%	-20%	-4%
370010000	17%	25%	-1%	-11%	-16%	0%	19%	4%	-20%	-4%
400000000	8%	35%	-4%	-23%	32%	-10%	14%	-3%	-12%	4%
500000000	24%	28%	-1%	-8%	-17%	-27%	19%	1%	-21%	-1%
578000000	33%	20%	-1%	-8%	-8%	-24%	20%	1%	-21%	-1%
600000000	29%	33%	0%	2%	23%	10%	25%	5%	-25%	-6%
678000000	16%	-47%	0%	1%	-34%	-29%	-1%	-1%	0%	1%
700000000	0%	-29%	0%	0%	-33%	-3%	10%	0%	-7%	2%
1170011000	2%	37%	0%	2%	-26%	-1%	5%	2%	-1%	-3%
1270011000	2%	37%	1%	-4%	-37%	-17%	4%	0%	-1%	0%
1370011000	14%	51%	0%	12%	-11%	18%	4%	0%	0%	1%
1470011000	7%	28%	1%	3%	0%	16%	2%	-1%	0%	2%
1570011000	-3%	54%	-3%	-12%	179%	-8%	-9%	-1%	6%	1%