

## VANADIUM

(Data in metric tons, vanadium content, unless otherwise specified)

**Domestic Production and Use:** Vanadium production in Utah from the mining of uraniferous sandstones on the Colorado Plateau ceased in early 2020 and was not restarted in 2024. Secondary vanadium production continued in Arkansas, Delaware, Ohio, Pennsylvania, and Texas, where processed waste materials (petroleum residues, spent catalysts, and utility ash) were used to produce ferrovanadium, vanadium-bearing chemicals or specialty alloys, and vanadium pentoxide. Estimated U.S. apparent consumption of vanadium in 2024 decreased by 8% from that in 2023. Metallurgical use, primarily as an alloying agent for iron and steel, accounted for more than 90% of domestic reported vanadium consumption in 2024. Of the other uses for vanadium, the major nonmetallurgical use was in catalysts to produce maleic anhydride and sulfuric acid.

| <b>Salient Statistics—United States:</b>                                 | <b>2020</b>      | <b>2021</b>      | <b>2022</b> | <b>2023</b>        | <b>2024<sup>e</sup></b> |
|--------------------------------------------------------------------------|------------------|------------------|-------------|--------------------|-------------------------|
| Production from primary ore and concentrate                              | 17               | —                | —           | —                  | —                       |
| Production from ash, residues, and spent catalysts <sup>e</sup>          | 2,900            | 3,200            | 4,400       | 6,500              | 8,200                   |
| Imports for consumption:                                                 |                  |                  |             |                    |                         |
| Aluminum-vanadium master alloy                                           | 101              | 35               | 104         | 221                | 110                     |
| Ash and residues <sup>1, 2</sup>                                         | 1,550            | 1,680            | 2,240       | 3,140              | 2,300                   |
| Ferrovanadium                                                            | 1,360            | 2,170            | 2,650       | 2,280              | 1,800                   |
| Oxides and hydroxides, other                                             | 67               | 69               | 222         | 151                | 170                     |
| Vanadium chemicals <sup>3</sup>                                          | 382              | 846              | 804         | 793                | 530                     |
| Vanadium metal <sup>4</sup>                                              | ( <sup>5</sup> ) | ( <sup>5</sup> ) | 28          | 20                 | 10                      |
| Vanadium ores and concentrates <sup>1</sup>                              | 2                | 4                | 492         | 674                | 160                     |
| Vanadium pentoxide                                                       | 1,670            | 1,710            | 1,980       | 2,320              | 2,500                   |
| Exports:                                                                 |                  |                  |             |                    |                         |
| Aluminum-vanadium master alloy                                           | 14               | 72               | 28          | 36                 | 70                      |
| Ash and residues <sup>1</sup>                                            | 503              | 930              | 1,130       | 861                | 1,500                   |
| Ferrovanadium                                                            | 210              | 173              | 154         | 159                | 70                      |
| Oxides and hydroxides, other                                             | 51               | 235              | 309         | 142                | 360                     |
| Vanadium metal <sup>4</sup>                                              | 1                | 4                | 8           | 38                 | 5                       |
| Vanadium ores and concentrates <sup>1</sup>                              | 92               | 81               | 185         | 82                 | 20                      |
| Vanadium pentoxide                                                       | 50               | 17               | 143         | 28                 | 120                     |
| Consumption:                                                             |                  |                  |             |                    |                         |
| Apparent <sup>6</sup>                                                    | 7,110            | 8,200            | 11,000      | 14,800             | 14,000                  |
| Reported                                                                 | 7,920            | 8,030            | 7,510       | <sup>e</sup> 8,000 | 8,000                   |
| Price, average, vanadium pentoxide, <sup>7</sup> dollars per pound       | 6.47             | 8.17             | 9.29        | 7.50               | 5.45                    |
| Stocks, yearend <sup>8</sup>                                             | 269              | 271              | 248         | 240                | 250                     |
| Net import reliance <sup>9</sup> as a percentage of apparent consumption | 59               | 61               | 60          | 56                 | 40                      |

**Recycling:** Recycling of vanadium is mainly associated with reprocessing vanadium catalysts into new catalysts. The range in vanadium content in spent catalysts varies depending on the crude oil feedstock and the uncertainty associated with the quantity of vanadium recycled from spent chemical process catalysts was significant.

**Import Sources (2020–23):** Ferrovanadium: Canada, 48%; Austria, 37%; Russia, 7%; and other, 8%. Vanadium pentoxide: Brazil, 49%; South Africa, 35%; Russia, 7%; and other, 9%. Total: Canada, 34%; Brazil, 13%; Austria, 11%; South Africa, 11%; and other, 31%.

| <b>Tariff:</b> | <b>Item</b>                                 | <b>Number</b>    | <b>Normal Trade Relations<br/>12–31–24</b> |
|----------------|---------------------------------------------|------------------|--------------------------------------------|
|                | Vanadium ores and concentrates              | 2615.90.6090     | Free.                                      |
|                | Vanadium-bearing ash and residues           | 2620.40.0030     | Free.                                      |
|                | Vanadium-bearing ash and residues, other    | 2620.99.1000     | Free.                                      |
|                | Vanadium pentoxide, anhydride               | 2825.30.0010     | 5.5% ad valorem.                           |
|                | Vanadium oxides and hydroxides, other       | 2825.30.0050     | 5.5% ad valorem.                           |
|                | Ferrovanadium                               | 7202.92.0000     | 4.2% ad valorem.                           |
|                | Vanadium metal                              | 8112.92.7000     | 2% ad valorem.                             |
|                | Vanadium and articles thereof <sup>10</sup> | 8112.99.2000     | 2% ad valorem.                             |
|                | Vanadium chemicals                          | ( <sup>3</sup> ) | 5.5% ad valorem.                           |

**Depletion Allowance:** 22% (domestic), 14% (foreign).

**Government Stockpile:** None.

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**Events, Trends, and Issues:** The estimated average Chinese vanadium pentoxide ( $V_2O_5$ ) price (98%  $V_2O_5$  content) in 2024 was \$5.45 per pound compared with \$7.50 in 2023. The estimated United States ferrovanadium price (78%–82% vanadium content) was \$12.84 per pound in 2024 compared with \$16.42 in 2023. The World Steel Association estimated that global steel consumption increased by 1.7% in 2024. Total world steel production was estimated to have decreased by 1.5% during the first 7 months of 2024 compared with the same period in 2023. Like most ferroalloys, vanadium is largely dependent on the market characteristics of steel and specifically the Chinese steel industry. In 2024, China continued to be the world's top vanadium producer, producing most of its vanadium from vanadiferous iron ore processed for steel production.

Vanadium redox flow battery (VRFB) technology continued to be an increasingly important part of large-scale energy storage as it allows for high-safety, large-scale, environmentally friendly, medium- and long-term energy storage. Installations of VRFB projects continued to increase worldwide as energy companies looked to support renewable energy projects as many countries attempt to lower their carbon emissions. Many governments worldwide are promoting energy storage technologies, which creates favorable conditions for VRFB adoption. However, high capital and operating costs as well as limited vanadium feedstock availability remain the main drawback of VRFB technology. Despite the anticipated growth of VRFBs, there will be continued competition from a variety of alternative battery technologies looking to capture a portion of the energy storage market share.

**World Mine Production and Reserves:** Reserves for China and South Africa were revised based on company and Government reports.

|                       | Mine production     |                   | Reserves <sup>11</sup><br>(thousand metric tons) |
|-----------------------|---------------------|-------------------|--------------------------------------------------|
|                       | 2023                | 2024 <sup>e</sup> |                                                  |
| United States         | —                   | —                 | 45                                               |
| Australia             | —                   | —                 | <sup>12</sup> 8,500                              |
| Brazil                | 5,420               | 5,000             | 120                                              |
| China                 | <sup>e</sup> 70,000 | 70,000            | 4,100                                            |
| Russia                | <sup>e</sup> 20,000 | 21,000            | 5,000                                            |
| South Africa          | 8,670               | 8,000             | 430                                              |
| World total (rounded) | 104,000             | 100,000           | 18,000                                           |

**World Resources:**<sup>11</sup> World resources of vanadium exceed 63 million tons. Vanadium occurs in deposits of phosphate rock, titaniferous magnetite, and uraniferous sandstone and siltstone, in which it constitutes less than 2% of the host rock. Significant quantities are also present in bauxite and carboniferous materials, such as coal, crude oil, oil shale, and tar sands. Because vanadium is typically recovered as a byproduct or coproduct, demonstrated world resources of the element are not fully indicative of available supplies.

**Substitutes:** Steels containing various combinations of other alloying elements can be substituted for steels containing vanadium. Certain metals, such as manganese, molybdenum, niobium (columbium), titanium, and tungsten, are to some degree interchangeable with vanadium as alloying elements in steel. Platinum and nickel can replace vanadium compounds as catalysts in some chemical processes. Currently, no acceptable substitute for vanadium is available for use in aerospace titanium alloys.

<sup>e</sup>Estimated. — Zero.

<sup>1</sup>Reported by the U.S. Census Bureau as kilograms of  $V_2O_5$ . To convert  $V_2O_5$  content to vanadium content, multiply by 0.56.

<sup>2</sup>Includes estimates for data suppressed by the U.S. Census Bureau in the years 2020 through 2024.

<sup>3</sup>Includes Harmonized Tariff Schedule of the United States codes for chloride oxides and hydroxides of vanadium (2827.49.1000), hydrides and nitrides of vanadium (2850.00.2000), vanadates (2841.90.1000), vanadium chlorides (2827.39.1000), and vanadium sulfates (2833.29.3000).

<sup>4</sup>Includes waste and scrap.

<sup>5</sup>Less than ½ unit.

<sup>6</sup>Defined as primary production + secondary production + imports – exports ± adjustments for industry stock changes.

<sup>7</sup>Chinese annual average  $V_2O_5$  prices (98%  $V_2O_5$  content). Source Argus Media Group, Argus Non-Ferrous Markets.

<sup>8</sup>Includes ferrovanadium, vanadium-aluminum alloy, other vanadium alloys, vanadium metal, vanadium pentoxide, and other specialty chemicals.

<sup>9</sup>Defined as imports – exports ± adjustments for industry stock changes.

<sup>10</sup>Aluminum-vanadium master alloy consisting of 35% aluminum and 64.5% vanadium and is the main master alloy for the vanadium industry.

Unwrought aluminum-vanadium master alloy (Harmonized Tariff Schedule of the United States code 7601.20.9030) was not included.

<sup>11</sup>See Appendix C for resource and reserve definitions and information concerning data sources.

<sup>12</sup>For Australia, Joint Ore Reserves Committee-compliant or equivalent reserves were 3 million tons.