Ukraine, Neon, and Semiconductors

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Neon gas is a critical input for the semiconductor industry due to its use in lasers. One of the largest sources of neon is the steel industry, where it is a byproduct of liquid oxygen generation. As of 2022, Ukraine supplies an estimated 50 percent of neon worldwide, which is largely attributable to the legacy of the Soviet steel industry. The U.S. semiconductor industry is dependent on this portion of the global value chain, as Ukraine produces nearly all of the ultra-high-purity semiconductor-grade neon imported by the United States. This executive briefing explains neon capture, its chief downstream application (i.e., lasers), and Ukraine's importance in the neon supply chain.

Neon Capture: Neon is a rare gas, comprising 0.0018 percent of the atmosphere. Separating it from other atmospheric gasses, like oxygen and nitrogen, involves a process akin to a home dehumidifier—liquefaction. In liquefaction, air is progressively cooled and compressed until each component gas condenses at its boiling point. Only the largest air separation units (ASUs) include neon capture systems because neon's low concentration in air means that smaller ASUs will not produce commercial quantities.[1] Large ASUs have historically been co-located with steel manufacturing, as the basic oxygen steelmaking process requires a high volume of pure oxygen obtained through this type of gas separation.

Neon Market: While neon is universally associated with brightly colored signage, its largest downstream application is lasers.[2] The semiconductor industry accounts for up to 90 percent of neon gas laser demand. In manufacturing semiconductor chips, a mixture of gases (termed *excimer gas*) generates the single wavelength of light used for deep ultraviolet photolithography.[3] Within the gas mixture, neon is typically a buffer and carrier gas that helps minimize defects during the photolithography process, increasing the overall yield of usable chips. U.S. manufacturers that use excimer gas must verify it meets their requirements for purity and quality. Qualification of a gas source can take 3 to 18 months, and if a customer were to switch sources, the process would have to be redone.

Ukraine: Ukraine supplies approximately half of the world's neon and is a major source of the ultra-high-purity neon used in chip manufacturing. Over the past decade, it has been estimated that Ukraine has supplied up to 90 percent of U.S. imports of neon. Ukraine also exports substantial volumes to major chip producing nations in Asia (see figure 1). The current conflict in Ukraine raises concerns about the security of that supply.

The 2014 Russian occupation of Crimea helps inform what could happen to the neon market in the near future. Ukraine supplied about 70 percent of neon to chipmakers globally in 2014. The largest Ukrainian gas purifiers at that time, Cryoin and Iceblick, were located in the Black Sea port city of Odessa, west of the peninsula. After the occupation, neon prices reportedly spiked over 600 percent. Delayed shipments combined with border crossing issues (between the Russia-Ukraine border) further compounded tight supplies at that time. Prior to the present conflict between Ukraine and Russia, Cryoin (still operational) and a company called Ingas were major suppliers of neon to U.S. customers. As of March 11, 2022, Cryoin and Ingas, have been unable to continue production.[4] It is likely that the present conflict will have a substantial impact on the global neon market, which will affect the semiconductor value chain.

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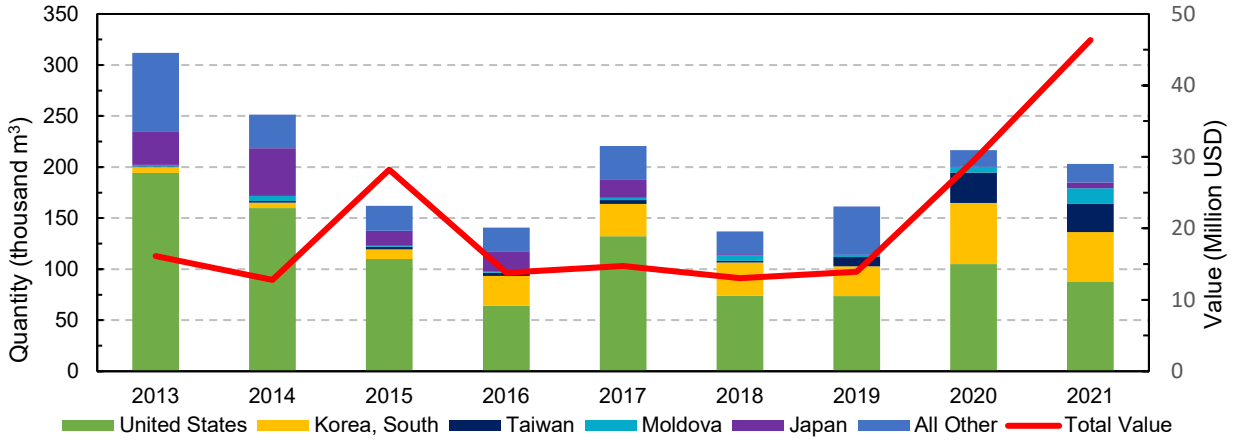
[1] Scarcity of neon in the atmosphere is due to its low density and inertness, which impede accumulation.

[2] Liquid neon can also be used as a cryogenic refrigerant.

[3] Photolithography is the process of using light to transfer patterns to silicon wafers via a photomask. Excimer gas mixtures for lithography are most commonly ArF (193 nm) or KrF (248 nm).

[4] It appears that Iceblick's neon operations are no longer occurring.

Figure 1: Ukrainian exports of rare gases quantity (cubic meters, m^3), value (dollars), and unit value



	2013	2014	2015	2016	2017	2018	2019	2020	2021
Unit Value ($/m³)	52	51	174	98	67	95	86	136	228

Source: Official exports statistics from Ukraine under HS heading 2804.29, as reported national statistical authorities in the Global Trade Atlas database, accessed March 4, 2021. Data may be overstated as HS heading 2804.29 contains trade other rare gases isolated via air separation (i.e., krypton and xenon).

Diversification of Supply: After 2014, some chip manufacturers diversified their neon sources, and Ukraine has since lost about 20 percent of global market share.[5] China has added significant capacity over the past decade, and at least one U.S. firm has expanded domestic production of neon.[6] Reportedly, the primary barrier for market entry is the scarcity of neon which limits the number of commercially viable neon purification sites. There is also an issue of scale: the U.S. excimer gas market only amounts to about $40 million, despite its overall criticality to laser gases.

The global capacity added since 2014 has not diminished U.S. reliance on Ukrainian semiconductor-grade neon. As of 2022, reports indicate that Ukraine was still the source for nearly all of semiconductor grade neon imported by the United States.[7] Additionally, six months ago, China shuttered steel mills to reduce pollution before the Winter Olympics and suppress demand for Australian iron ore, reportedly tripling neon prices into Q1 of 2022. The full extent of the neon gas bottleneck will depend on the overall course of the ongoing conflict, how rapidly Ukrainian production can restart, and when Ukrainian neon can re-enter the global market.

Sources: Fukuda, "Chipmakers Seek Solution," March 2016; Solid State Technology, "Neon Shortage Coming," February 2016; Diglogs, "Odessa, the Neon of War," March 8, 2022; Meaker, "Russia's War," March 4, 2022; FT reports, "Russia's Invasion," March 3, 2022; Yonhap, "Ukraine Tensions," February 24, 2022; Pimlott, "Linde Installs," July 19, 2016. Federal Trade Commission, "Analysis of Proposed Agreement," October 22, 2018; Moggridge, "Praxair Announces," August 20, 2020; Sterling, "ASML Seeking Alternative Sources," February 23, 2022; Alper and Freifeld, "Russia Could Hit," February 11, 2022; King, "Ukraine Invasion Rattles," March 2, 2022.

[5] Some firms have attempted to mitigate risk by stockpiling neon as well.

[6] Linde Gas AG installed neon production in Texas in 2016. Linde and Praxair announced in 2018 that they were merging, together representing about 70 percent of U.S. excimer gas production. The status of the previously announced investment is unclear.

[7] In comparison, Dutch firm ASML reportedly sources only 20 percent of its neon from the Russia-Ukraine region.