Substance Flow Analysis of Tantalum in Taiwan

Feng-Chi Yen, Tien-Chin Chang* and Wen-Hong Xu

Institute of Environmental Engineering and Management, National Taipei University of Technology, Taipei 106, Taiwan

Substance Flow Analysis (SFA) is mainly used to quantify flows and stocks of a particular substance distributed in a finite ecosystem. It can also be used to help decision-makers select the best strategy to implement resource allocation and management. This study focused on tantalum flow in Taiwan in 2013, specifically as tantalum capacitors, powder, and waste products. Tantalum, a rare metal that has a lot of potential, especially in the electronics industry, is not locally produced in Taiwan; so an SFA is vital to monitor supply, demand, and accumulation. Best estimates were done in coordination with Taiwan companies and government agencies, namely: Ministry of Economic Affairs; Ministry of Finance; Customs Department; and Environmental Protection Administration. In 2013, Taiwan imported a total of 340,355 kg of tantalum; 84.5% of this remained in Taiwan either as electronic products or as raw materials, while the rest were exported.
[\[doi:10.2320/matertrans.M2015420\]](https://doi.org/10.2320/matertrans.M2015420)

(Received November 26, 2015; Accepted February 15, 2016; Published April 8, 2016)

Keywords: tantalum capacitors, substance flow analysis, rare metal tantalum, powder

1. Introduction

Tantalum, a gray-blue high-density hard metal, with melting point of 3017°C and boiling point of 5458°C, is classified as a scarce resource. According to US Geological Survey, tantalum in the Earth's crust has limited natural reserves of 400,000 tons, with even more limited recoverable reserves of more than 43,000 tons¹⁾. Varied industry characteristics of different countries cause varying definitions of scarce resources, but Table 1 summarizes these definitions. Scarce resources are also vulnerable to different supply policies and political considerations that could result to price volatility^{2,3)}. It is important to understand that there are no official prices for tantalum commodities, as this metal is not traded on any metal exchange. The price is determined solely by negotia-

tions between buyer and seller⁴⁾.

The major use of tantalum is for electronic components such as capacitors and high power resistors, because, as metal powder, it has a tendency to form a protective oxide surface layer. In 2012, tantalum, primarily as powder and capacitors, had global production of about 765 tons. Mozambique, Brazil, Congo, Rwanda, and Nigeria are the main producers accounting for more than 80% of the world production^{5,6)}. Taiwan, despite relying solely on imports, is also a major player in the use of tantalum, being one of the leading countries to manufacture semiconductor wafers and optoelectronic components. It has also developed the related production and recovery technology of high purity tantalum powder. To understand the flow of the pulsating tantalum scarce resources and explore the possibility of efficient recovery⁷⁾ of precious metals, this research work concentrated on the tantalum substance flow analysis (SFA). SFA is a systematic assessment of the flows and stocks of materials within a system defined in space and time⁸⁾. One of its major applications is in resource management, specifically on analysis, planning, allocation, exploitation, and upgrading of resources⁹⁾. This research aims to assess relevant flows and stocks of tantalum quantitatively, checking mass balance, sensitivities, and uncertainties. The results could be used by Taiwan government as basis for managing tantalum resource and wastes, monitoring accumulation or depletion of stocks and future environmental loadings. The results could also be used to design environmentally-beneficial goods, processes, and systems¹⁰⁾.

2. Methodology and Data Source

SFA assists decision-makers to investigate and understand storage and flow of materials in a specified system. It asks whether the flow of materials is sustainable in terms of the environmental burden it creates. It accounts for all materials and energy used in production and consumption, including the hidden flows or ecological rucksack of materials that were extracted in the production cycle but which never entered into the final products. This system includes: input, output, and stock¹¹⁾; basic analysis of the SFA program^{12,13)}; and steps described in Fig. 1 below:

Table 1 Definition of scarce resource.

Factor		Explanation	Scarce Resources
Ore resource reserves	Endowments, distribution and production be concentrated in a few countries	Less content in the earth's crust and difficult to mine	Platinum
		Distributed in a few countries	Tantalum
Demand	Add a small amount in the manufacturing process, features and performance of products dramatically increase	Exploration and production in a few countries	Thallium
		Few production in full year	Rhenium
International Factors	Affected by countries supply policy and political considerations.	Suppliers Resources Protectionism	Beryllium
		Political restrictions on exports	Indium
Technology	Extraction, separation, difficult processing that only a few countries have these technology	difficulties of refining and processing technical	Palladium
		It has cutting-edge technology	Molybdenum

Source of the materials: T.C Chang

*Corresponding author, E-mail: tcchang@ntut.edu.tw

Fig. 1 SFA framework for tantalum in Taiwan in 2013.

Table 2 Tariff No. of products containing tantalum.

Tariff No.	Description
81032000	tantalum powders
81033000	tantalum waste and scrap
85322100	tantalum capacitors

2.1 Identification of System Boundaries

Tantalum SFA in Taiwan is limited to year 2013.

2.2 Identification of components of the system

Components include import, export, and accumulation. These components can be any of the tantalum-containing products classified as powder, waste, or capacitor based on the tariff number classifications, as shown in Table 2.

2.3 Identification of Constraints

Legal constraints on the responsibilities of enterprises, manufacturers, and importers as regards recycling, clearance, and disposal of products, help to reduce the uncertainty on estimation and calculation of material flow distribution and improve the accuracy of statistical scale.

At present, there is still no relevant tantalum SFA database available in Taiwan and available information was insufficient to specify uncertainty for some stock and flow data¹⁴⁾. However, based on the authors' judgment on data sensitivity, highly confidential data include official data from different government agencies in Taiwan, surveyed data from different companies, and estimated or validated data mainly based on official data and surveyed data. Lower confidential data include the market share of different companies that could be prejudiced by company image, among others. However, all data in the results have been validated by careful mass balance.

2.4 Data acquisition and inventory

Aside from literature search and market research, the two major sources of information for this study are: (1) government agencies; and (2) High-Tech companies in Taiwan.

Government agencies that provided data on import and export of tantalum in Taiwan include Ministry of Economic Affairs; Ministry of Finance; Customs Department; and Environmental Protection Administration.

High-tech companies in Taiwan are listed in Table 3. These companies provided enough information for the estimation of the total tantalum used for the manufacture of capacitors, using eqs. (1) and (2).

$$Ta_{Tcap} = \sum Ta_{pdt} \quad (1)$$

$$Ta_{pdt} = \frac{SA}{MS}(0.15) \quad (2)$$

where: Ta_{Tcap} is the total amount of tantalum in capacitors in Taiwan for the year 2013; Ta_{pdt} is the amount of tantalum in a specific product; SA is the surveyed amount of each type of product, based on interview with different companies; MS is the market share of that specific product; and 0.15 is the 15% tantalum content of capacitors as recommended by the companies to be used for the estimation, as shown in Table 4.

From the total amount of imported tantalum, the amount of non-capacitor products (powder) can be computed using eq. (3).

$$Ta_{powder} = Ta_{Timp} - (Ta_{cap} + Ta_w) \quad (3)$$

where Ta_{Timp} is the total amount of imported tantalum; Ta_{cap} is the total amount of tantalum in capacitors; and Ta_w is total amount of tantalum in waste or scrap.

Tantalum powder is high-purity tantalum powder that is free of impurities. In this study, tantalum powder or simply

Table 3 High-tech companies surveyed.

Tantalum-containing material	Companies
Import	Tantalum Capacitors
	Accton Technology Corporation
	Panasonic Taiwan Corporation
	Allreach Enterprise Corporation
	Tantalum Powder
	Qi Xiu Enterprises Corporation
	Opetech Materials Corporation
	Solar Technology
	JX Nippon Mining & Metals Corporation
	Solar Technology Corporation
	Tantalum Scrap
	Qi Xiu Enterprises Corporation
	Jii Yeeh Ding Enterprise Corporation
	Laurels Carry & Leap International Corporation
Manufacture	Semiconductor Wafers
	Solar Technology Corporation
	Taiwan Semiconductor Manufacturing Company
	Vanguard International Semiconductor Corporation
	Switch-type Power Supply
	Finesse Technology Corporation
	Cincon Electronics Corporation
	Charger
	Cincon Electronics Corporation
	Rear Projection Machine
	Lumens Digital Optics Incorporated
	Other Electronic Products
	Might Electronic Corporation
	Billion Electric Corporation
Export	Tantalum Capacitors
	ROHM Semiconductor
	Allreach Enterprise Corporation
	Satori Electric Corporation
	Tantalum Scrap
	Qi Xiu Enterprises Corporation
	Laurels Carry & Leap International Corporation
	Tantalum Powder
	JX Nippon Mining & Metals Corporation
	Ding Yu Industrial Corporation
	Yi Shibo International Business Corporation
Waste	Tantalum Scrap
	Qi Xiu Enterprises Corporation
	Jii Yeeh Ding Enterprise Corporation
	Laurels Carry & Leap International Corporation

Table 4 Tantalum content of different products.

Products containing tantalum	Tantalum content (%)	Reference
Tantalum pentoxide	81.9%	molecular weight
Tantalum powder	100%	provided by industry
Tantalum target	100%	provided by industry
Tantalum Capacitors	15%	provided by industry

Table 5 Taiwan 2013 imports of products containing tantalum.

Product	kg	%
Tantalum capacitors	200,357	58.87
Tantalum powder	139,911	41.11
Tantalum waste and scrap	87	0.03
Total	340,355	100.00

“powder” is used to refer to “non-capacitor” products, or products other than capacitors that are containing tantalum.

The amount of waste can be computed using eq. (4).

$$w_T = \sum w_{\text{imp}} + w_{\text{cap}} + w_{\text{powder}} \quad (4)$$

where w_T is the total amount of tantalum in waste that will be exported; w_{imp} is the amount of imported tantalum in waste or scrap; w_{cap} is the amount of tantalum in the waste in the production of capacitors; and w_{powder} is the amount of tantalum in the waste in the production of non-capacitor products.

The amount of tantalum accumulation in Taiwan for 2013 can then be computed using eq. (5).

$$Ta_{\text{acc}} = Ta_{\text{Timp}} - Ta_{\text{Tex}} \quad (5)$$

where Ta_{acc} is tantalum accumulation in Taiwan; Ta_{Timp} is the total amount of imported tantalum; and Ta_{Tex} is the total amount of exported tantalum.

3. Results and Discussion

According to the ROC Ministry of Finance Directorate General of Customs, in 2013, Taiwan imported a total of 340,355 kg of tantalum, as shown in Table 5. This table also shows the major categories of tantalum products: capacitors and powder. Tantalum powder represents all tantalum in Tai-

wan other than those in capacitors. Thus, tantalum powder is also referred to as non-capacitors. This simplification was done for better tracking of tantalum flow in coordination with leading companies and government agencies in Taiwan. Tantalum capacitors accounted for 200,357 kg of tantalum, which is about 59% of total tantalum import. The other 41% was attributed to tantalum powder (139,911 kg). Out of the total imported amount, 87 kg was waste and scrap; and this is less than 1% of the total imported amount of tantalum.

In 2013, the domestically available tantalum capacitors were all imported, since there were no local manufacturers. Using eqs. (1) and (2), the estimated total amount of tantalum capacitors (200,357 kg) was computed. Table 6 shows the breakdown of this amount into specific products. eq. (2) factored in three (3) important items: SA; MS; and 0.15. SA is the surveyed amount of each type of product shown in Table 6. These amounts were the results of meticulous survey from leading high-tech companies in different industries in Taiwan (Table 3) that also disclosed their estimated market share (MS) for different products. Due to confidentiality agreement, these specific values cannot be shown in this paper. These two values, SA and MS were used to compute for the estimated total market of capacitors for each product in the different industries. The last item to be factored in was the 15% tantalum content of capacitors. This information was given by Holy Stone Enterprise Co., Ltd that claims that capacitors contain an average of 15% tantalum by weight. Equation (1) was then used to get the total amount of tantalum in capacitors in Taiwan for the year 2013. Table 6 gives the summary of the estimated amount of tantalum per product

using data from industry survey, factoring in the market share of the particular company surveyed to estimate the total production in Taiwan. From Table 6, it can be seen that tantalum capacitors is mostly used for switch-type power supply.

Table 6 Estimated amount of tantalum per product based on industry survey.

Ta-containing electronic products	Manufacturers	Estimated amount of Tantalum (kg/y)
Switch-type power supply	Finesse Technology Co., Ltd. Cincon Electronics Co., Ltd.	72,857
Charger	Cincon Electronics Co., Ltd	21,429
Rear Projection Machine	Lumens Integration, Inc.	19,286
Motherboard	BCM Computers Co., Ltd	17,143
Digital Projector	Lumens Integration, Inc.	9,643
Other electronic products	Might Electronics Co., Ltd.	60,000
Total		200,357

Table 7 Taiwan 2013 exports of products containing tantalum.

Product	kg	%
Tantalum capacitors	21,200	40.2
Tantalum powder	28,000	53.1
Tantalum waste and scrap	3,490	6.6
Total	52,690	100.0

Fig. 2 SFA of tantalum in Taiwan in 2013.

Then, using eq. (3), the amount of tantalum powder was computed. This was done by subtracting the accounted for amount of tantalum in capacitors from the total amount of imported tantalum.

Still in coordination with government agencies in Taiwan, data on exportation of tantalum was summarized in Table 7 that shows the exported amount of tantalum as capacitors, powder, or waste. The total exported amount of tantalum was 52,690 kg. For uniformity, the categories used in the summary of importation of tantalum were used for the exportation data. Capacitors, which amounted to 21,200 kg of tantalum, accounted for 40.2% of exported tantalum. Non-capacitors (powder) had 28,000 kg and accounted for 53.1% of exported tantalum. The remaining 6.6% of exported tantalum, which is equivalent to 3,490 kg, was wastes or scrap.

Using eq. (4), the total amount of tantalum in the waste or scrap was calculated. This is also by assuming, as recommended in the industry survey, that the waste production is 1% of the raw material. From this, the total accumulation of tantalum in Taiwan was computed using eq. (5). Figure 2 shows the complete SFA of tantalum in Taiwan for the year 2013. The total accumulated amount of tantalum in Taiwan for the year 2013 was 287,665 kg.

4. Conclusions

This study investigated the amounts and directions of tantalum flow within Taiwan in 2013.

- (1) Based on extensive survey and coordination with leading Taiwan companies and government agencies, the total import of tantalum in 2013, was 340,355 kg, while the total export was 52,690 kg.
- (2) From the total import, 287,665 kg of tantalum, or 84.5% remained in Taiwan economy in 2013. The major use of tantalum was in capacitor, accounting for 61.6%.
- (3) Accounting for waste generation, it was estimated at 3,490 kg of tantalum.

Acknowledgements

The data presented in this research was developed within the “Regional energy resource supply counseling application technology research and demonstration program” supported by the Industrial Development Bureau of the Ministry of Economic Affairs (Project 1030701). The authors also thank Holy Stone Enterprise Co., Ltd., Solar Technology, Inc and Sonjiu Electronic Co., Ltd. for sharing their experiences and providing valuable information regarding the use of tantalum in Taiwan.

REFERENCES

- 1) Larry D. Cunningham: Open-File Report 01-349, (Tantalum recycling in the United States in 1998, Flow Studies for Recycling Metal Commodities in the United States, U.S. Geological Survey).
- 2) T.C. Chang, C.Y. Lu and K.C. Peng: *J Ind Pollution Contr* **124** (2012) 175–198.
- 3) J. Lee, Y. Kim and J.C. Lee: *J. Hazard. Mater.* **241** (2012) 387–394.
- 4) “Tantalum - Raw Materials and Processing”. Tantalum-Niobium International Study Center. <http://tanb.org/tantalum>.
- 5) “Global Mining: Mozambique among 8 Top Tantalum-producing Countries”. Mozambique Resources Post. <https://mozambiqueiningpost.wordpress.com>.
- 6) “Mineral Resources Logistics”. Japan Oil, Gas and Metals National Corporation (JOGMEC) (2014) pp. 192–201.
- 7) J.Z. Li, P. Shrivastava, Z. Gao and H.C. Zhang: *IEEE T Electron Pack* **27** (2004) 33–42.
- 8) C. Hendriks, R. Obernosterer, D. Muller, S. Kytzia, P. Baccini and P.H. Brunner: *Local Environ.* **5** (2000) 311–328.
- 9) René Kleijn and Ester van der Voet: Material Flow Accounting, Paper presented at the NTVA 4th Seminar on Industrial Ecology, 2001 pp. 14–15.
- 10) U. Sonesson and J. Berlin: *J. Clean. Prod.* **11** (2003) 253–266.
- 11) H. Rechberger and P.H. Brunner: *Environ. Sci. Technol.* **36** (2002) 809–816.
- 12) P. Baccini and P.H. Brunner: *Metabolism of the Anthroposphere*, Springer-Verlag, Berlin, Heidelberg, 1991.
- 13) Minnesota Pollution Control Agency (MPCA), Substance Flow Analysis of Mercury in Products, MPCA, (2001) 1–22.
- 14) C. Huang, J. Vause, H. Ma, Y. Li and C. Yu: *J. Clean. Prod.* **84** (2014) 450–458.