Predicting Indium (In) and Tellurium (Te) Availability

Lindsey V. Maness, Jr.
Geologist
Golden, CO USA
LVManess@Comcast.net
www.China-Resources.net

Hubris or Humility

- Prior resources depletion predictions have been very inaccurate.
- Oil & gas depletion estimates are presented.
- USGS = "At Least" or "Minimum" resources.
- **Clarke Number** can Give "Maximum."
- New methodology presented more accurate.

Resources Depletion Predictions

- August 27, 1859: Oil officially discovered in Titusville, PA, USA
- 1901: Spindletop, TX. Giant oil field began producing more than all others at that time.
- 1914: US BOM predicted that all U.S. oil reserves would be depleted by 1924.
- 1939: The US DOI announced that the world had only 13 years of petroleum reserves left.
- 1951: The US DOI announced that the world had only 13 years of petroleum reserves left.
- 1977: Former President Carter predicted depletion of all the world's oil reserves by 1990.

Resources Depletion Reality

- 1970s-present: Canada's tar sands oil more than in Saudi Arabia. (New Economics.)
- 1980s-present: Dr. Jan Krason UN studies confirm that natural gas in clathrates (gas hydrates) will meet 1000s of Years of Demand. Presence known: Nobody cared. (Same Te & In)
- 2009: Marcellus Shale (WV-PA-NY) Gas Field may be as big as the largest ever discovered.
- Innumerable small-to-large discoveries cumulatively continue to meet our needs.

Methodology Conclusion

- The methodology used to officially forecast supplies of mineral commodities is **woefully inaccurate**.
  - Dependent solely upon (proven) resources.
  - Ignores probable new discoveries & technology.
- A new methodology to forecast supplies is presented herein.

Clarke Number

- **Frank Wigglesworth Clarke** (1847-1931) is considered to be the "***Father of Geochemistry***."

- The "***Clarke Number***" is an estimate of the amount of elements and compounds in the crust of the earth.

Data About the Earth

- Mean density of continental crust
  - $2.7\ g/cm^3 = 2.7(1x10^{-3})\ kg/(1x10^{-5})^3\ km^3 = 2.7 \times 10^{12}\ kg/km^3$
- Earth's land area
  - $1.49 \times 10^8\ km^2$
- Volume of earth's land area @ 3 km thickness
  - $4.47 \times 10^8\ km^3$
- Weight of earth's land area @ 3 km thickness
  - $(4.47 \times 10^8\ km^3)(2.7 \times 10^{12}\ kg/km^3) = 12.069 \times 10^{20}\ kg = 12.069 \times 10^{17}$ metric tons

Clarke Numbers for Selected Elements and ∑ Metric Tonnes in 3 km of Crust

	Parts Per Million	Metric Tonnes x 10^{11}
Arsenic (As)	1.8	21.72
Bismuth (Bi)	0.17	2.052
Cadmium (Cd)	**0.2**	**2.414**
Gallium (Ga)	**15**	**181.0**
Germanium (Ge)	**1.5**	**18.10**
Mercury (Hg)	0.08	0.9655
Indium (In)	**0.1**	**1.207**
Antimony (Sb)	0.2	2.414
Selenium (Se)	0.05	0.6035
Tin (Sn)	2	24.14
Tellurium (Te)	**0.01**	**0.1207**

Supply Formula

$$Ma(Mr/Ma)\{(Vf)(Vp)(Vd)(Vt)\} = \text{Predicted Supply}$$

- Ma = Maximum Amount of commodity = **Clarke Number** x tonnes in a specified volume.
- Mr = Maximum Recoverable Amount = Total amount recovered during historical times of an equivalent commodity.
- Vf = Variable, Financial $\geq 0.0000 \leq 1.0000$ = Availability of financing.
- Vp = Variable, Political Will $\geq 0.0000 \leq 1.0000$ = 1 - Political limitations imposed on extraction, processing, ….
- Vd = Variable, Concentration Ratio $\geq 0.0000 \leq 1.0000$ = Proportion concentrated by geological forces.
- Vt = Variable, Technology $\geq 0.0000 \leq 1.0000$.

Commodity Availability

(Preliminary Rough Estimate)

- ≥ 3 TW Necessary for World Energy Capacity.
- Module Lifetime ≈ **20 Years**.
- PV Market in 2010 ≈ **10 GW**.
- $Ma_{In}(Mr_{In}/Ma_{In})\{(Vf_{In})(Vp_{In})(Vd_{In})(Vt_{In})\} = (Mr_{In})$ (1.207 x 10^{11}) tonnes {(1.0)(1.0)(**0.01**)(1.0)} ≈ 0.12 x 10^{5} tonnes ≈ 10,000 GW = 10 TW ≈ **70 Years**.
- $Ma_{Te}(Mr_{Te}/Ma_{Te})\{(Vf_{Te})(Vp_{Te})(Vd_{Te})(Vt_{Te})\} = (Mr_{Te})$ (0.1207 x 10^{11}tonnes {(1.0)(1.0)(**0.1**)(1.0)} ≈ 0.12 x 10^{5} tonnes ≈ 10,000 GW = 10 TW ≈ **70 Years**.

Stages

- Exploration for **ore** (Economic concentration)
- Acquire properties/Permits
- Mine
- Concentrate/Process
- Smelt/Refine
- Sell to users
- Manufacture end products
- Market end products

Concentrate/Process Methods

- Specific gravity
- Size separation
- Magnetics
- Electrical (Electroplating, …)
- Flotation
- Retort (Decanting and vaporizing/condensing)
- Solution (Acids, bases, …)
- Centrifugation
- Oxidation/Reduction
- …

Flotation

Invented in 19th Century

- Used in concert with (after) other methods
- Finely ground concentrated ore
- Wide-Spectrum "*Soap*" *vs*. Narrow-Spectrum
  - Wide-Spectrum = All Sulfides
  - Narrow-Spectrum = One or Few Sulfide Minerals

Multiple Commodities Require Wide-Spectrum Flotation (e.g., Te, In, Ga, Ge, Sb, Se, Hg, Cd …)

Retort

(With or Without Vacuum)

- Commodities have different melting & vaporization temperatures
- Concentrate and separate multiple commodities cheaply and efficiently
- Low-tech, well-understood technology
- Patents long-expired

Melting & Vaporization °C

	Melting Point	Vaporization Point
Arsenic (As)	…	613 (Sublimates)
Bismuth (Bi)	271.3	~1,560
Cadmium (Cd)	320.9	765
Gallium (Ga)	29.78	2,403
Germanium (Ge)	937.4	2,830
Mercury (Hg)	-38.87	356.58
Indium (In)	156.61	~2,000
Antimony (Sb)	630.5	1,380
Selenium (Se)	217	~684.9
Tin (Sn)	231.89	2,270
Tellurium (Te)	~449.5	~989.8

Indium & Tellurium

Exploration Targets

Indium	Tellurium	Explanation
Yes	Yes	Metallic massive sulfides (Pb-Zn-Ag-Cu-Ni)
Yes	Yes	Au-Ag-Cu tellurides
Yes	No	Sn mines
No	Yes	*Frasch Process* sulfur (~0.5% is Se + Te + …)
No	Yes	Sour crude processed sulfur
Yes	Yes	Metals mine waste dumps
Yes	Yes	Smelter waste piles
Yes	Yes	Coal waste dumps (high-sulfur)

Synergy/Relationships

- Te, In, As, Ga, Ge, Sb, …, tend to occur together with chalcophile elements (O, S, Se, Te …).
- In also occurs preferentially in Sn Oxide deposits.
- **O-S-Se-Te are in a single column in the periodic chart of elements, meaning they have pronounced chemical similarity.**
- Volatility of Te, In, As, Ga, Ge (retort implications)
- Multiple-commodity production should be considered for Te, In, As, Ga, Ge.

Areas of Major Potential (US)

- Ducktown, TN (**Massive Sulfides**)
- Leadville, CO (**Massive Sulfides**)
- Joplin, MO (**Massive Sulfides**)
- WV, IL, IN (High-Sulfur Coal Waste Dumps)
- Hydrothermal Deposits (CA, NV, CO, …)

{Note: **EPA's Brownfields Program** provides Incentives to remediate contaminated sites.}

<<**Note: World's best may be mountainous Cu-slag heaps on Cyprus (*e.g.*, Troodos).**>>

Production Necessities

- Existence of desired commodities in economic concentrations, etc.
- Logistics (roads, electrical, water, labor, …)
- Availability of properties for mining
- Financing
- Permitting (regulations & legalities)
- **An assured long-term market**

ANY NUMBER TIMES ZERO IS ZERO.

(Richness of deposits is irrelevant if …)

- Mine development funding is unavailable.
- Permits cannot be acquired. (**Political Will**)
- Permits are delayed for years.
- Access to properties is prevented.
- Sales cannot be made by mines to PV buyers.

Recommendations

- Continue research on mineralized areas and mine/smelter waste dumps, etc., to enable generation of reasonable supply/demand data.
- Create a **Commodities Exchange** for the semiconductor (PV) elements to bestow confidence that materials produced will be salable at a reasonable price.

Potential Sources of Information

- United States Geological Survey (*esp*. Library)
- {former} US Bureau of Mines (reports)
- Indium Corporation
- First Solar (Te database probably extensive)
- National Renewable Energy Laboratory
- Lindsey Maness' Web-Site

http://www.China-Resources.net

Conclusions

Insufficient Data to Plot Supply/Demand Curves

Synergistic Relationships Further Complication

- Ample tellurium (Te) for foreseeable future.
- Ample indium (In) for foreseeable future.
- Further research is necessary on mineralized areas and development of new techniques.

Reality Check

In & Te Exist in Quantity, BUT!!!

Any Number times 0 = 0

- Vf = Variable, **Financial** $\geq 0.0000 \leq 1.0000$ = Availability of Financing.
- Vp = Variable, **Political Will** $\geq 0.0000 \leq 1.0000$ = 1 - Political Limitations Imposed on Extraction, Processing, ….
- **Recycling** & improved efficiency is necessary.
- **Non-geological shortages are very probable.**

Predicting Indium (In) and Tellurium (Te) Availability

Lindsey V. Maness, Jr.
Geologist
Golden, CO USA
LVManess@Comcast.net
www.China-Resources.net