



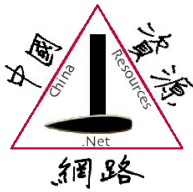
# Predicting Indium (In) and Tellurium (Te) Availability

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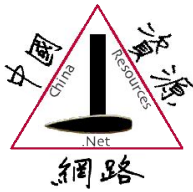
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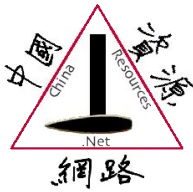
# *Hubris or Humility*

- 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.



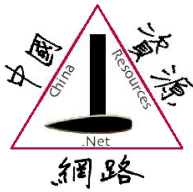
# Resources Depletion Predictions

- 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.



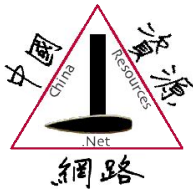
# Resources Depletion Reality

- 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.



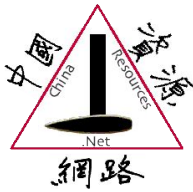
# Methodology Conclusion

- 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.



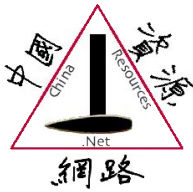
# Clarke Number

- **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

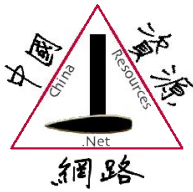
- Mean density of continental crust
  - $2.7 \text{ g/cm}^3 = 2.7(1 \times 10^{-3}) \text{ kg}/(1 \times 10^{-5})^3 \text{ km}^3 = 2.7 \times 10^{12} \text{ kg/km}^3$
- Earth's land area
  - $1.49 \times 10^8 \text{ km}^2$
- Volume of earth's land area @ 3 km thickness
  - $4.47 \times 10^8 \text{ km}^3$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



# Clarke Numbers for Selected Elements and $\Sigma$ Metric Tonnes in 3 km of Crust

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

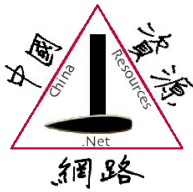




# Supply Formula

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

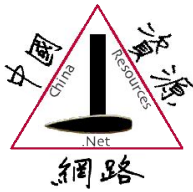
- $Ma$  = Maximum Amount of commodity = **Clarke Number** x tonnes in a specified volume.
- $Mr$  = Maximum Recoverable Amount = Total amount recovered during historical times of an equivalent commodity.
- $Vf$  = Variable, Financial  $\geq 0.0000 \leq 1.0000$  = Availability of financing.
- $Vp$  = 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

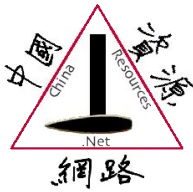
(Preliminary Rough Estimate)

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



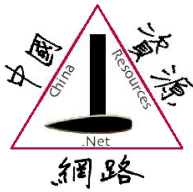
# Stages

- 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
- ...

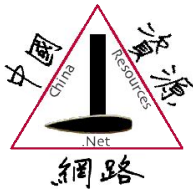


# Flotation

Invented in 19<sup>th</sup> 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

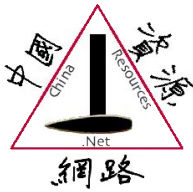
(With or Without Vacuum)

- 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

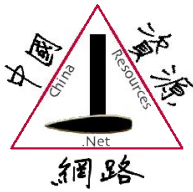


# Indium & Tellurium

## Exploration Targets

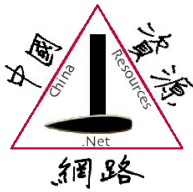
Indium	Tellurium	Explanation
Yes	Yes	Metallic massive sulfides (Pb-Zn-Ag-Cu-Ni)
Yes	Yes	Au-Ag-Cu tellurides
Yes	No	Sn mines
No	Yes	<i>Frasch Process</i> sulfur (~0.5% is Se + Te + ...)
No	Yes	Sour crude processed sulfur
Yes	Yes	Metals mine waste dumps
Yes	Yes	Smelter waste piles
Yes	Yes	Coal waste dumps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

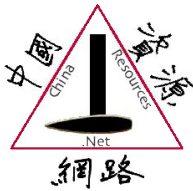


# Conclusions

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

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





# Predicting Indium (In) and Tellurium (Te) Availability

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