Ex China Vanadium Market

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Ferroalloynet.com Vanadium Forum

Chengde, China

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Objectives

- Communicate the drivers affecting changes to vanadium consumption outside of China
- Vanadium consumption outside of China
- Production of vanadium outside of China
- China vanadium exports
- Total vanadium supply outside of China
- Vanadium demand outside of China
- Vanadium supply/demand balance outside of China
- Vanadium flow batteries
- New applications for vanadium
- Summary

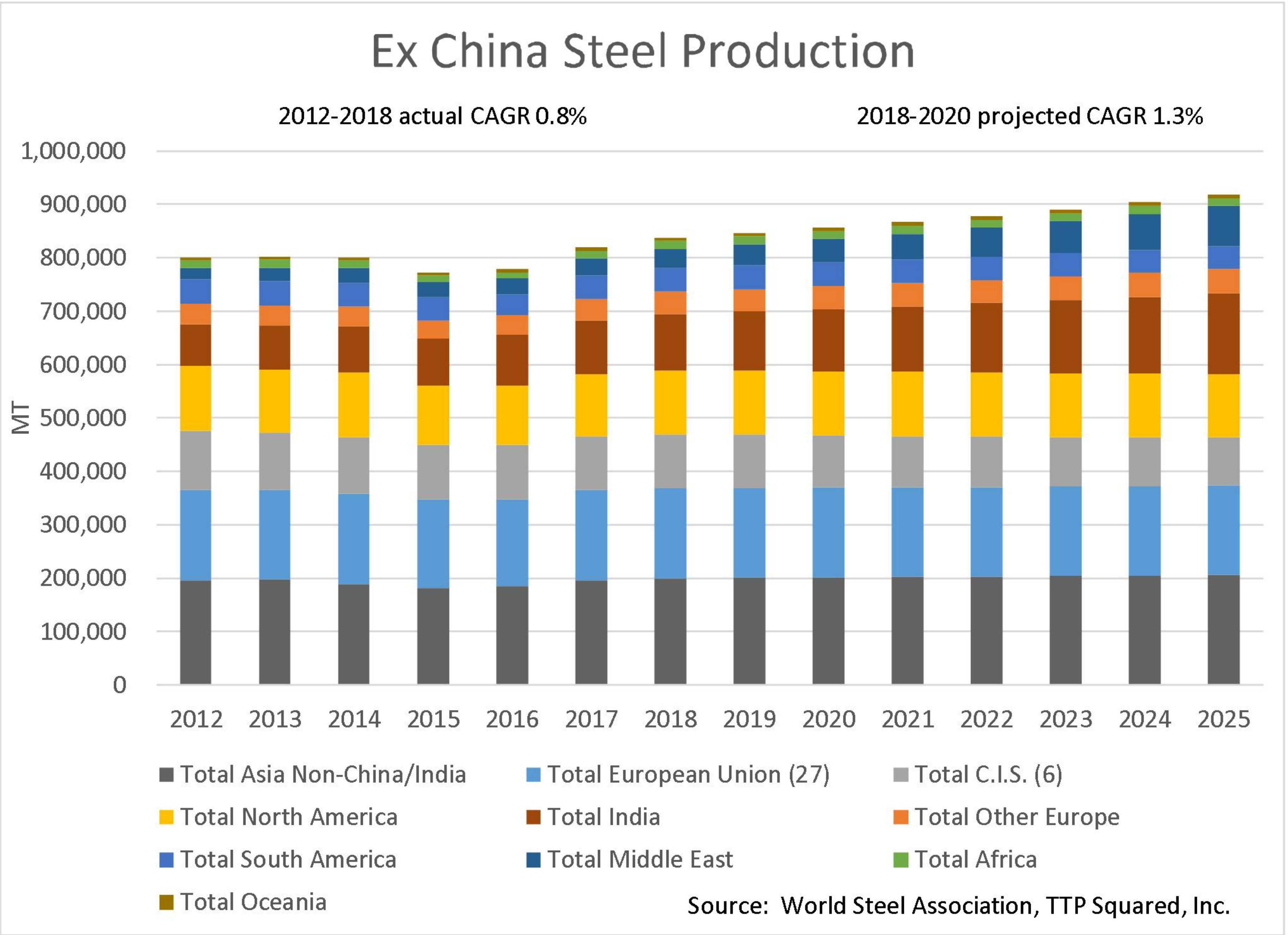
Vanadium Consumption ex China

Vanadium Consumption

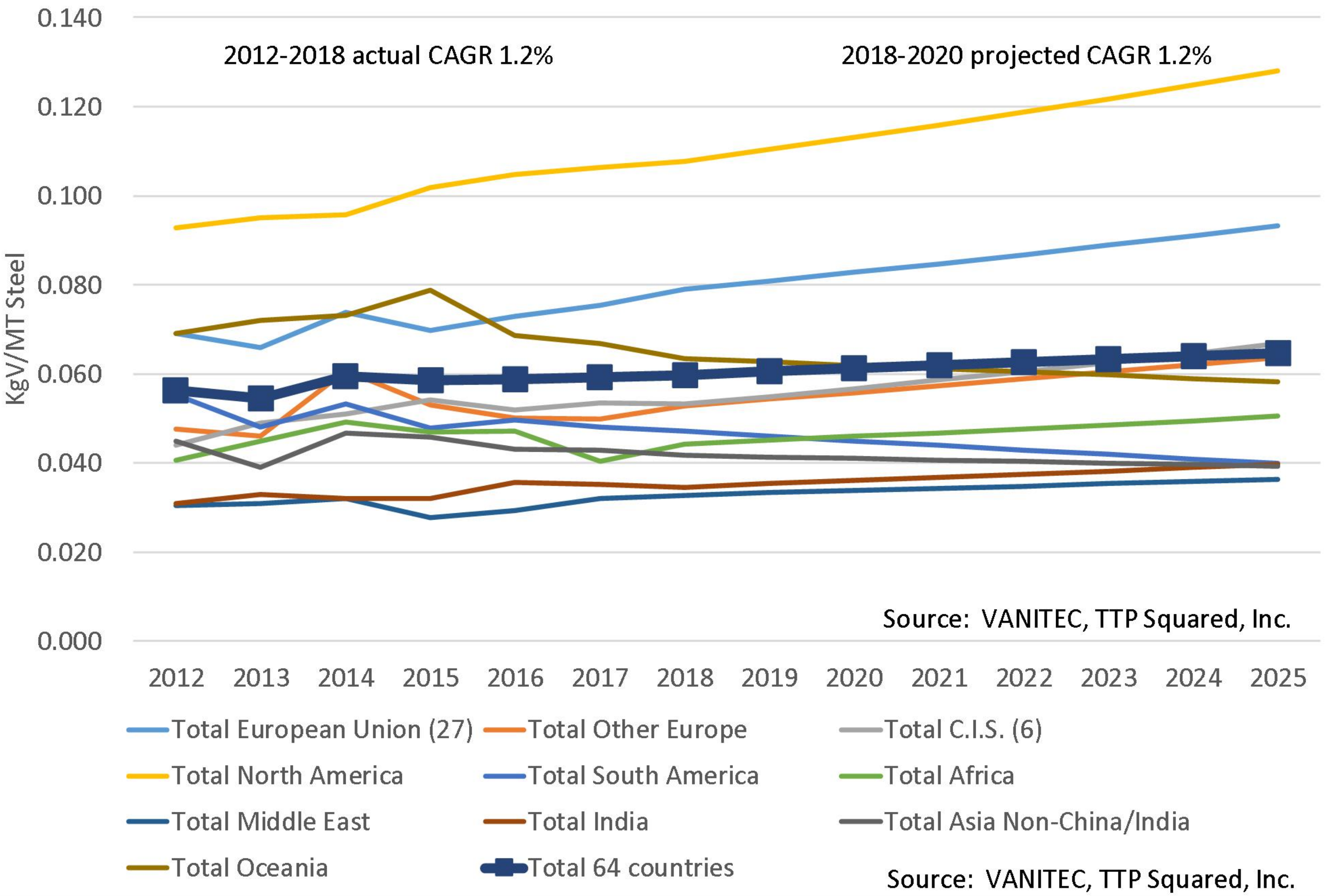
- Roughly 90% of current vanadium consumption occurs in the steel industry.
- Roughly 4% of annual vanadium consumption occurs in the titanium industry where vanadium is used to make titanium alloys for commercial aerospace, defense, industrial applications and consumer goods
- Roughly 4% of vanadium consumption occurs in the chemical and catalyst industries where vanadium is used as an oxidation catalyst in production of sulfuric acid and maleic anhydride, in pollution control catalysts and Benfield and Stretford processes in the petrochemical industry
- Roughly 2% of vanadium consumption currently occurs in energy storage applications where vanadium redox flow batteries are being deployed in grid level applications

Drivers to growth in ex China V Consumption

- Changes in ex China steel production volumes
- Changes in ex China specific vanadium consumption rates
- Potential new applications


Ex China Steel Production
2012-2018 actual CAGR 0.8%
2018-2020 projected CAGR 1.3%
MT
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Total Asia Non-China/India
Total European Union (27)
Total C.I.S. (6)
Total North America
Total India
Total Other Europe
Total South America
Total Middle East
Total Africa
Total Oceania
Source: World Steel Association, TTP Squared, Inc.

Specific Vanadium Consumption Rate



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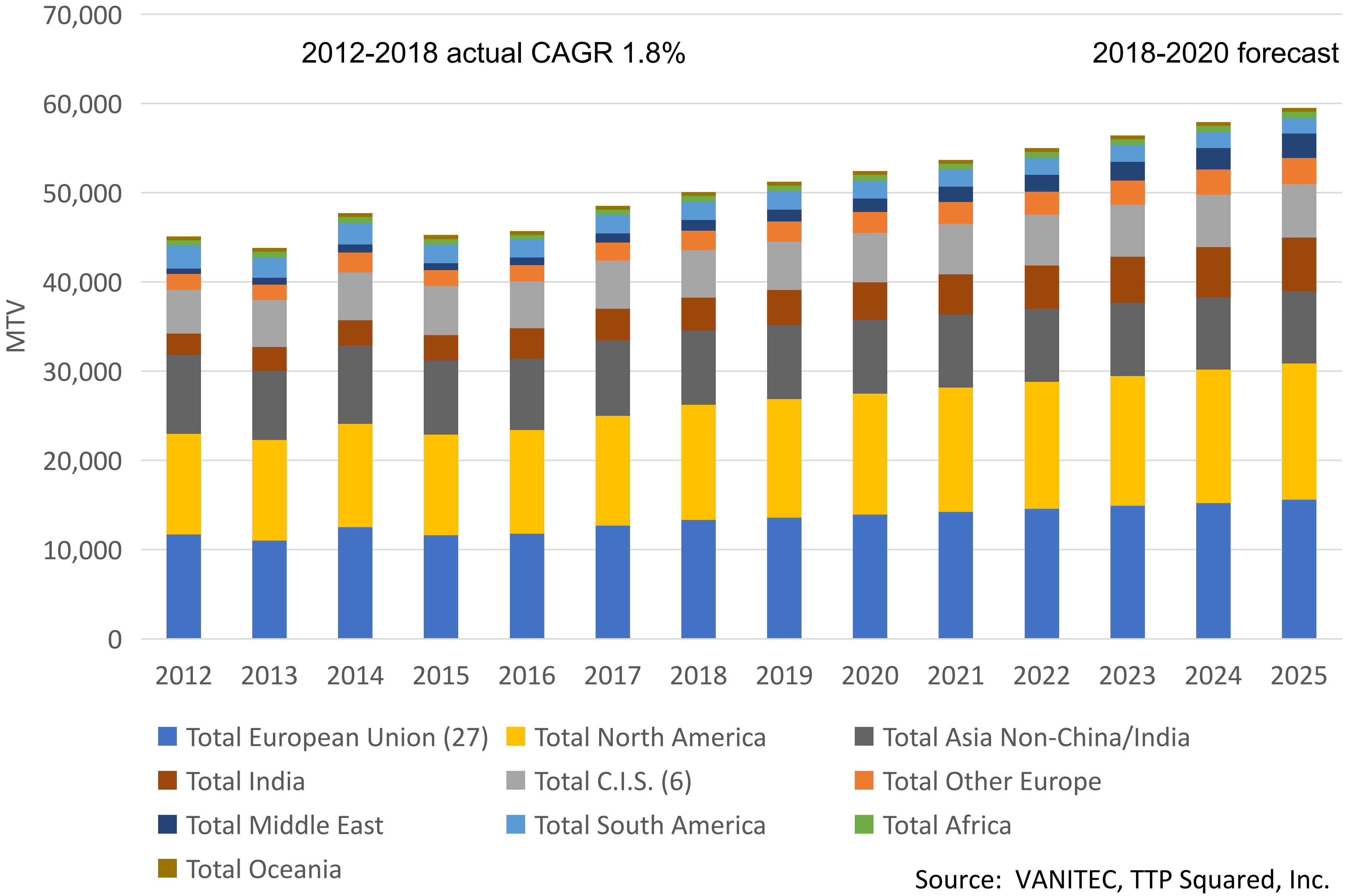
Vanadium Consumption ex China



Source: VANITEC, TTP Squared, Inc.

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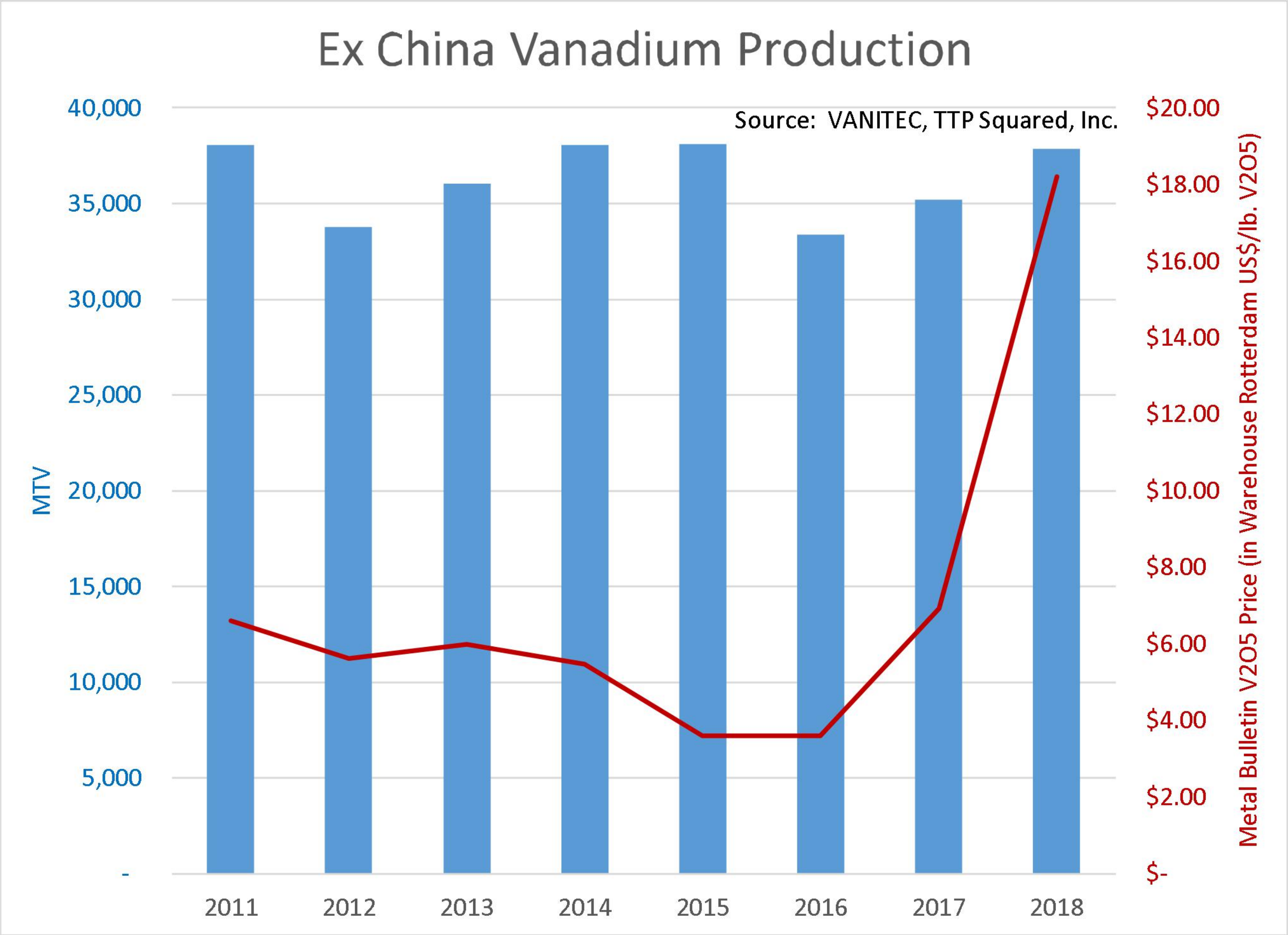
Ex China Vanadium Consumption Summary

- Ex China steel production has grown by 0.8% compound annual growth rate (CAGR) 2012-2018. We expect ex China steel production to grow at a CAGR of 1.3% 2018-2025
- The ex China specific vanadium consumption rate has grown at a CAGR of 1.2% 2012-2018. our projection assumes a specific consumption growth rate ex China of 1.2% in the near future
- Vanadium consumption ex China has grown at a CAGR of 1.8% from 2012-2018. We expect ex China vanadium consumption to grow from 50,075 metric tons vanadium (MTV) in 2018 to 59,494 MTV in 2025 (2.5% CAGR)

ex China Vanadium Production



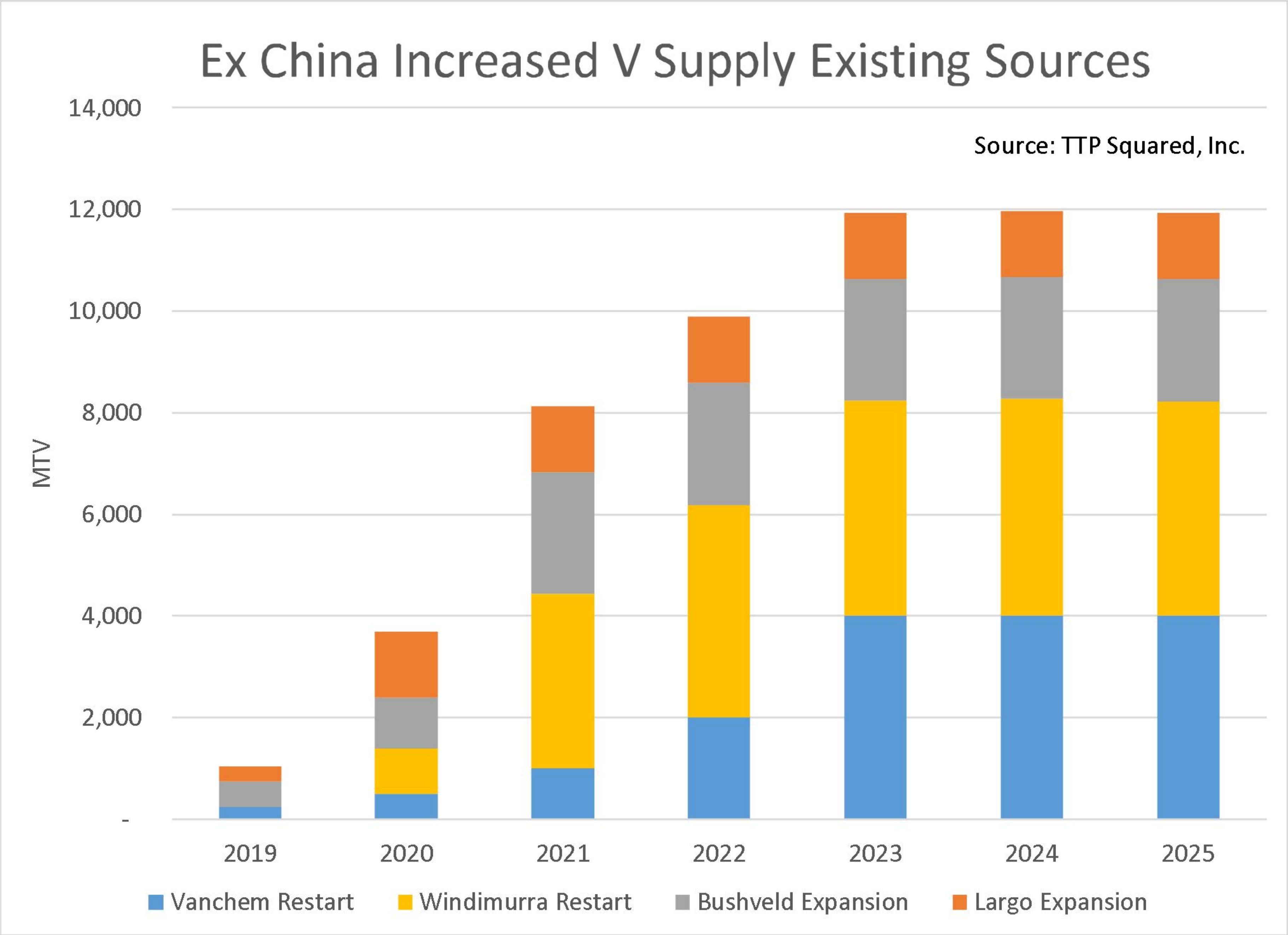
Ex China Vanadium Production
Source: VANITEC, TTP Squared, Inc.
MTV
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
-
$20.00
$18.00
$16.00
$14.00
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$-
Metal Bulletin V2O5 Price (in Warehouse Rotterdam US$/lb. V2O5)
2011
2012
2013
2014
2015
2016
2017
2018

ex China Vanadium Production History

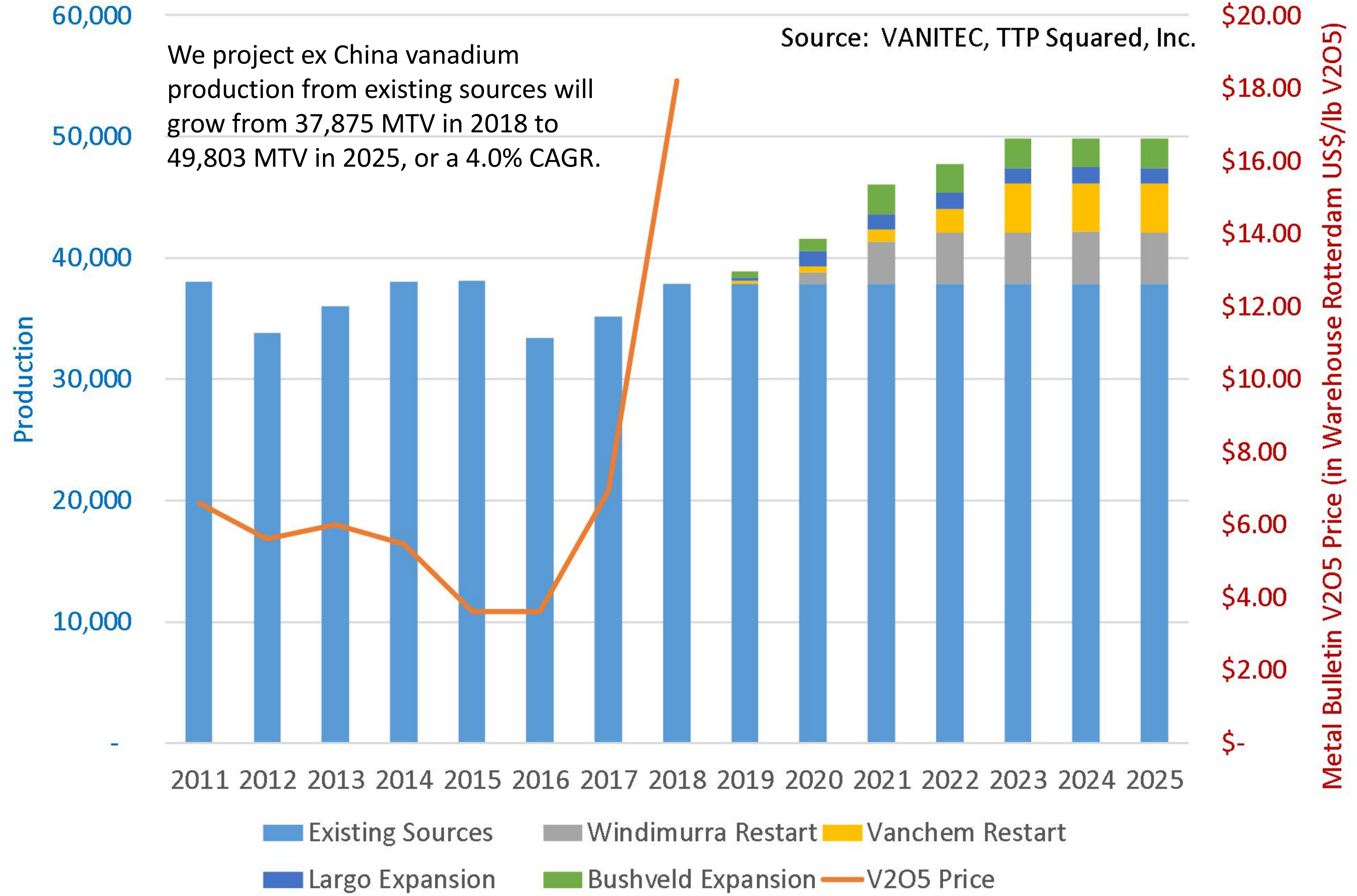
- Vanadium production ex China has varied from 33,000 – 38,000 MTV from 2011-2018.
- The demise of Highveld Steel in South Africa had a major impact on global vanadium supply beginning in 2015.
- The ramp up of production at the Largo Maracas mine in Brazil has allowed ex China vanadium production to recover in 2018 to close levels seen in 2014-2015
- Looking forward there are limited sources of supply ex China that can contribute in the near term to increased production

Ex China – Short Term New Sources of Production

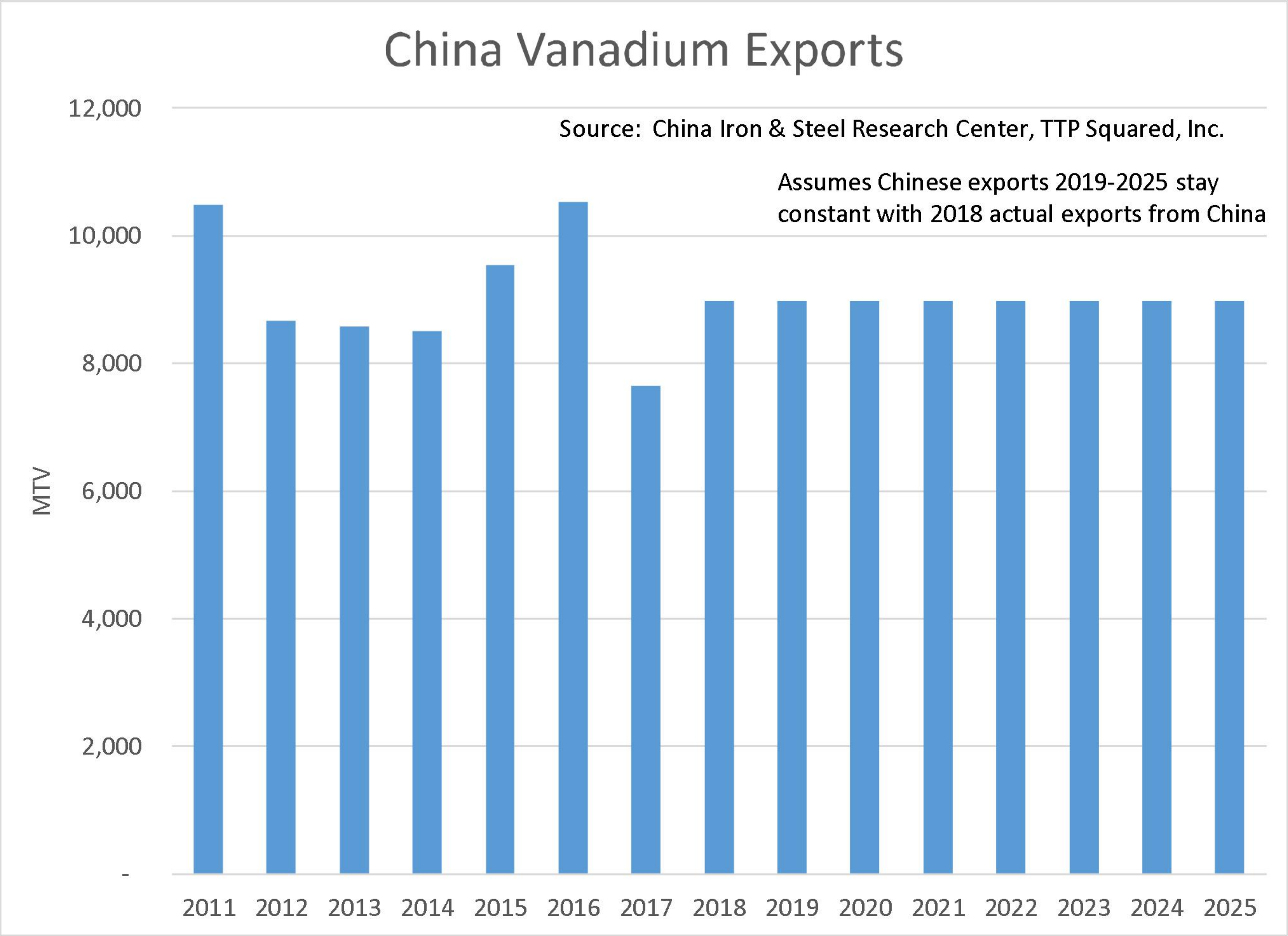
- Vanadium production is limited by the availability of economically viable raw materials.
- In the near term there are limited sources of potential new vanadium raw materials outside of China.
  - Largo resources has announced plans to expand the Maracas mine in Brazil in late 2019 by 20% or an increase of 1,350 MTV/yr.
  - Bushveld has announced plans to expand the Vametco mine by 2,000 MTV in the coming years
  - We Anticipate eventually Vanchem in South Africa will find a way to feed their plant from South African ores resulting in an increase in supply of 4,000 MTV/yr.
  - Windimurra in western Australia has announced plans to restart and eventually reaching 4,200 MTV/yr. production rate


Ex China Increased V Supply Existing Sources
Source: TTP Squared, Inc.
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
MTV
2019
2020
2021
2022
2023
2024
2025
Vanchem Restart
Windimurra Restart
Bushveld Expansion
Largo Expansion

Ex China V Production Existing Sources



China Vanadium Exports



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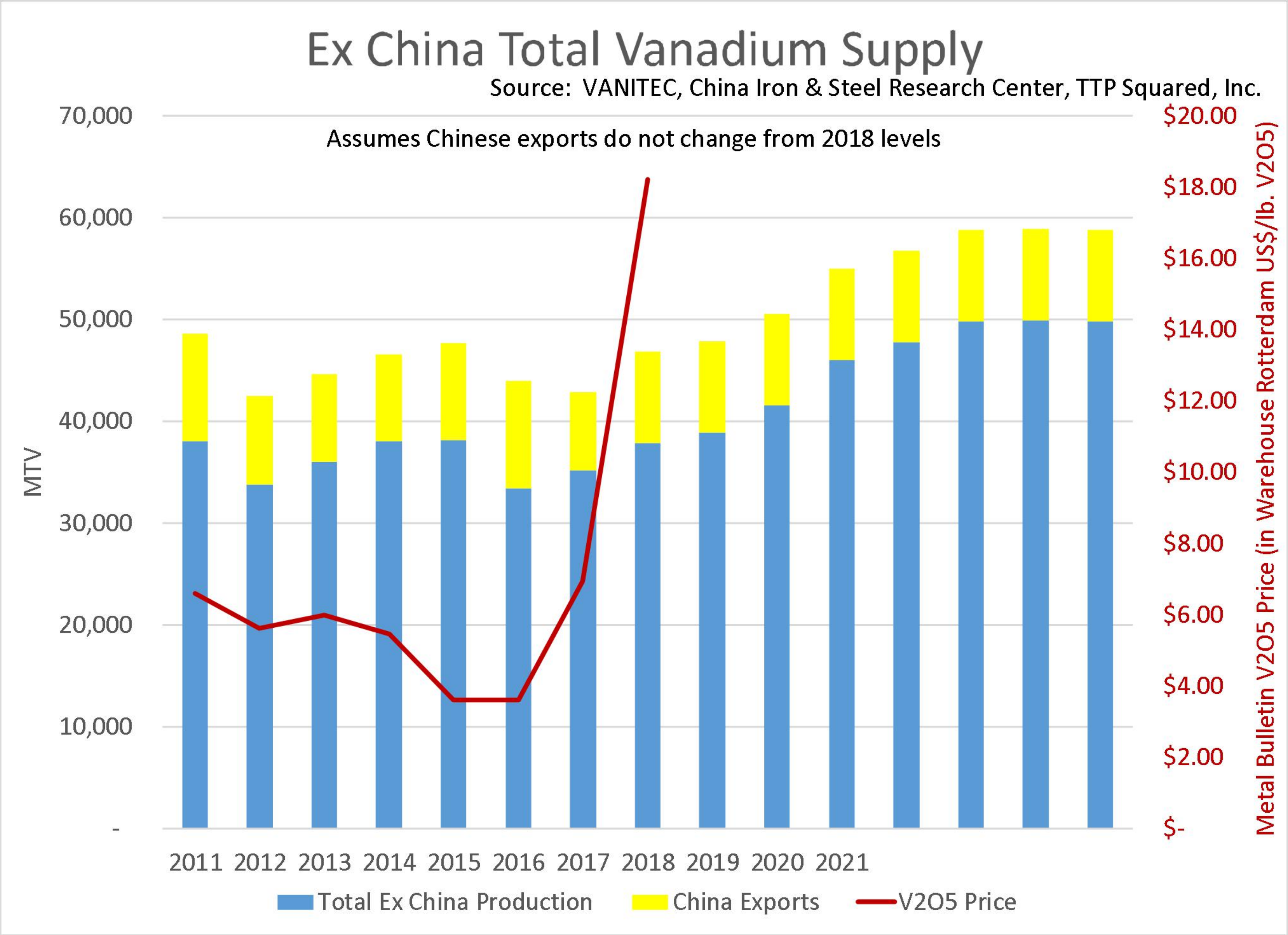
Chinese Vanadium Exports

- Chinese net exports of vanadium have varied from 7,500 MTV to 10,500 MTV per year in recent years
- Chinese exports decreased in 2017 as a result of the ban on imports of vanadium slag and residues used as raw material for vanadium production in China
- Exports increased to more typical levels in 2018 as high prices resulted in the liquidation of inventories.
- **Our projection for the future makes the assumption that Chinese vanadium exports will be constant at the 2018 level of roughly 9,000 MTV per year**
- As a result we see total supply of vanadium ex China growing from 46,848 MTV in 2018 to 58,776 MTV in 2025, or a CAGR of 3.3%


Ex China Total Vanadium Supply
Source: VANITEC, China Iron & Steel Research Center, TTP Squared, Inc.
Assumes Chinese exports do not change from 2018 levels
MTV
70,000
60,000
50,000
40,000
30,000
20,000
10,000
-
$20.00
$18.00
$16.00
$14.00
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$-
Metal Bulletin V2O5 Price (in Warehouse Rotterdam US$/lb. V2O5)
2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Total Ex China Production
China Exports
V2O5 Price

Ex China Supply and Demand Balance

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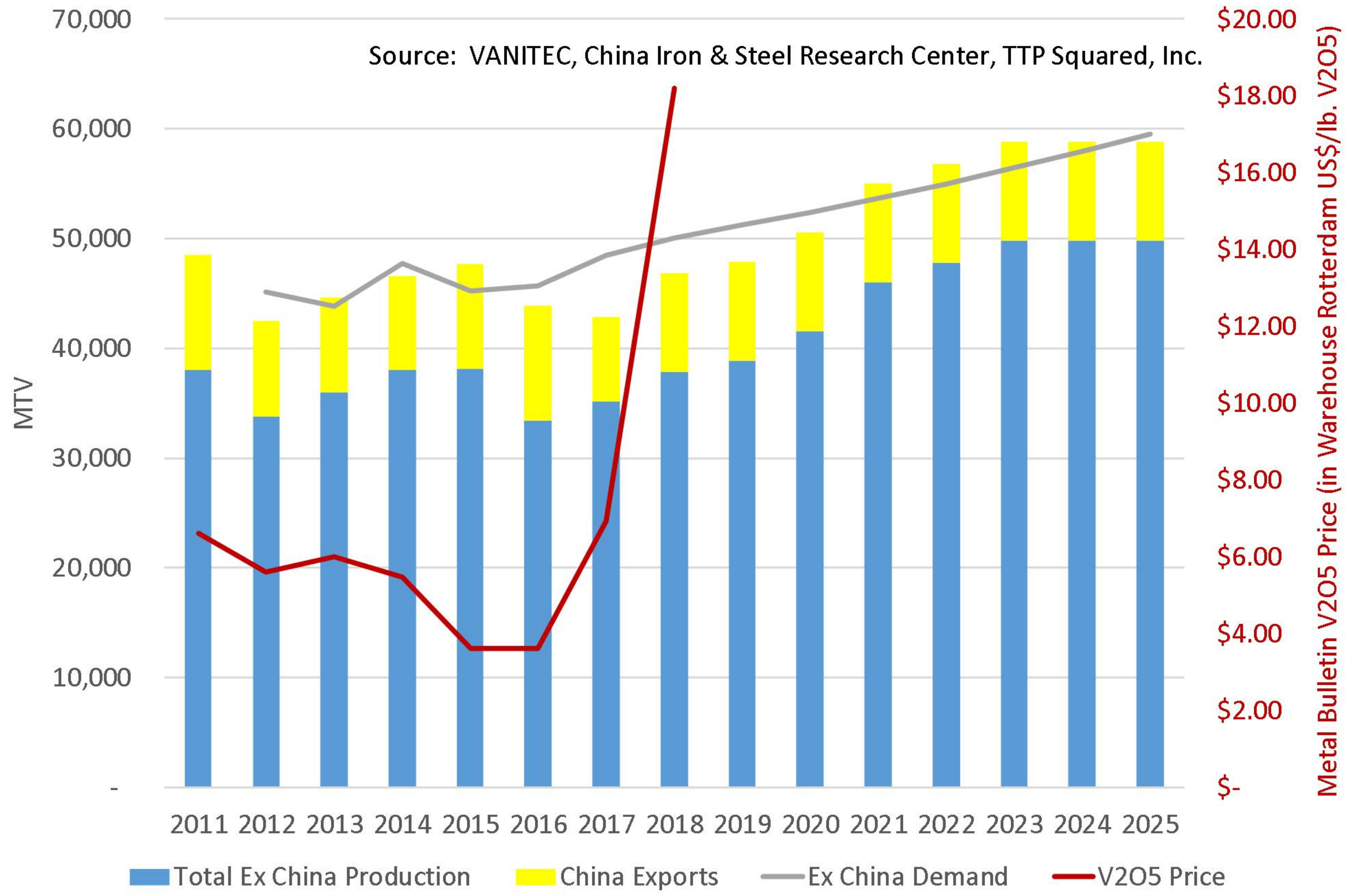
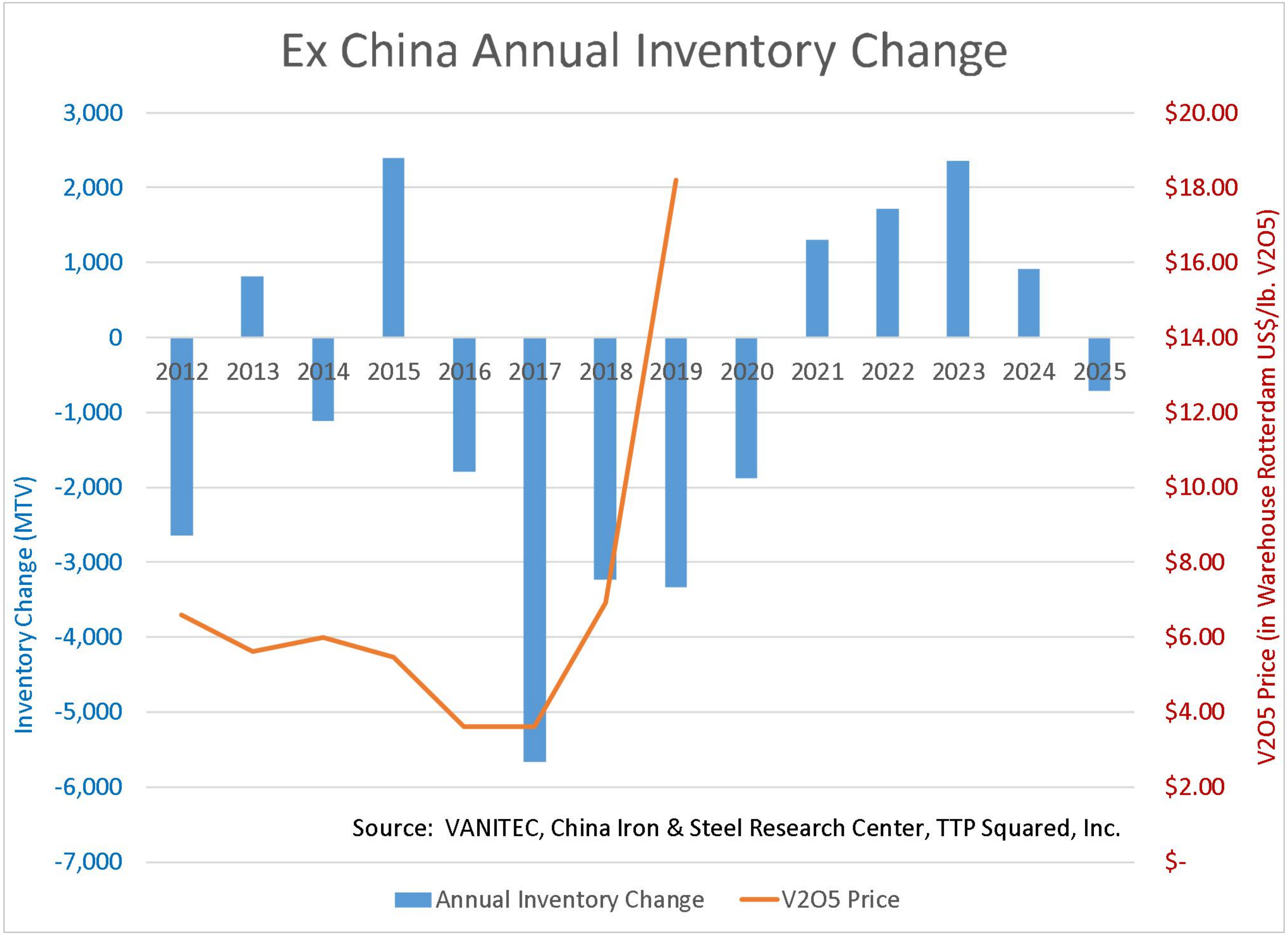
Ex China V Supply Existing Sources vs Demand





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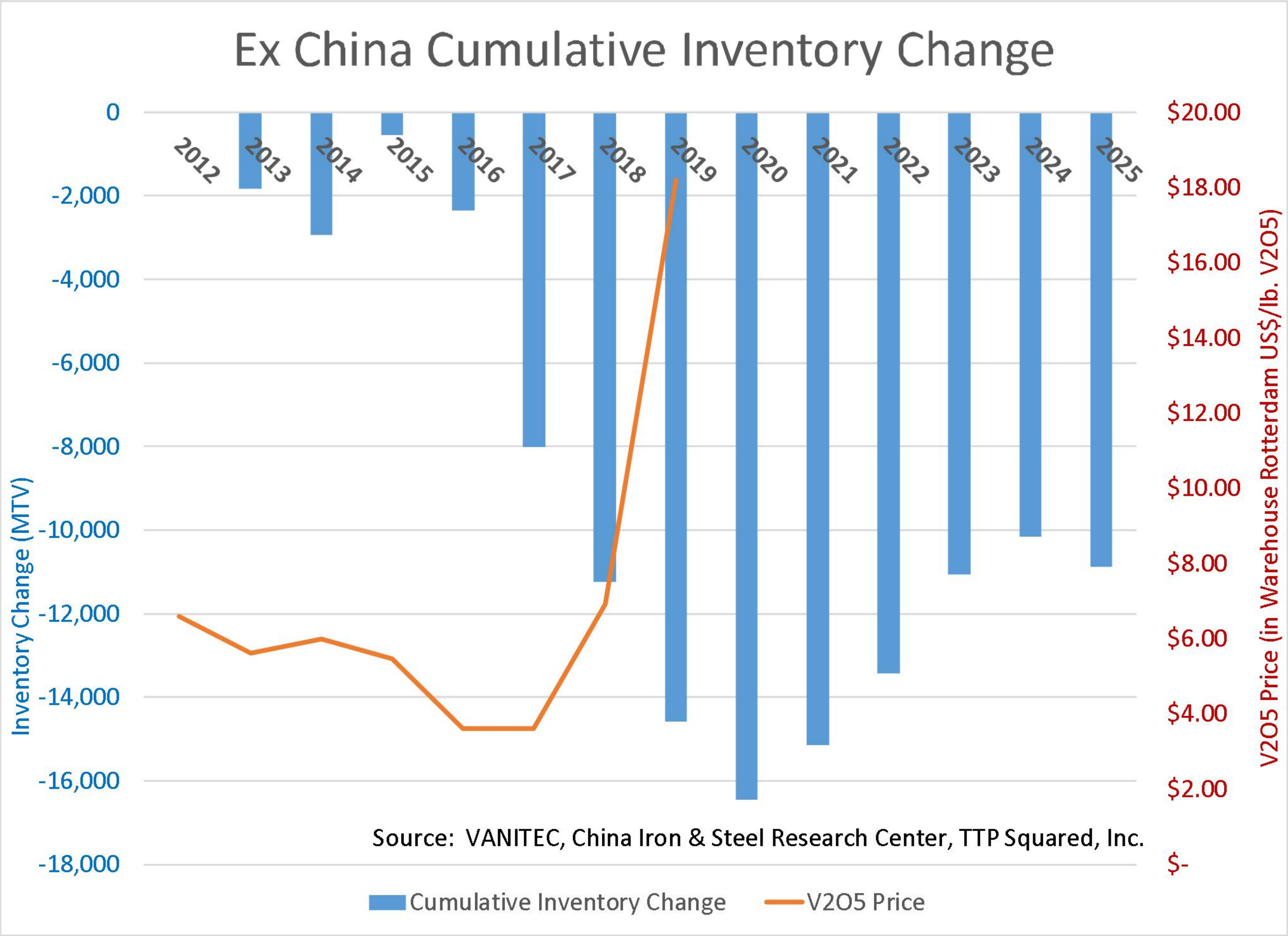
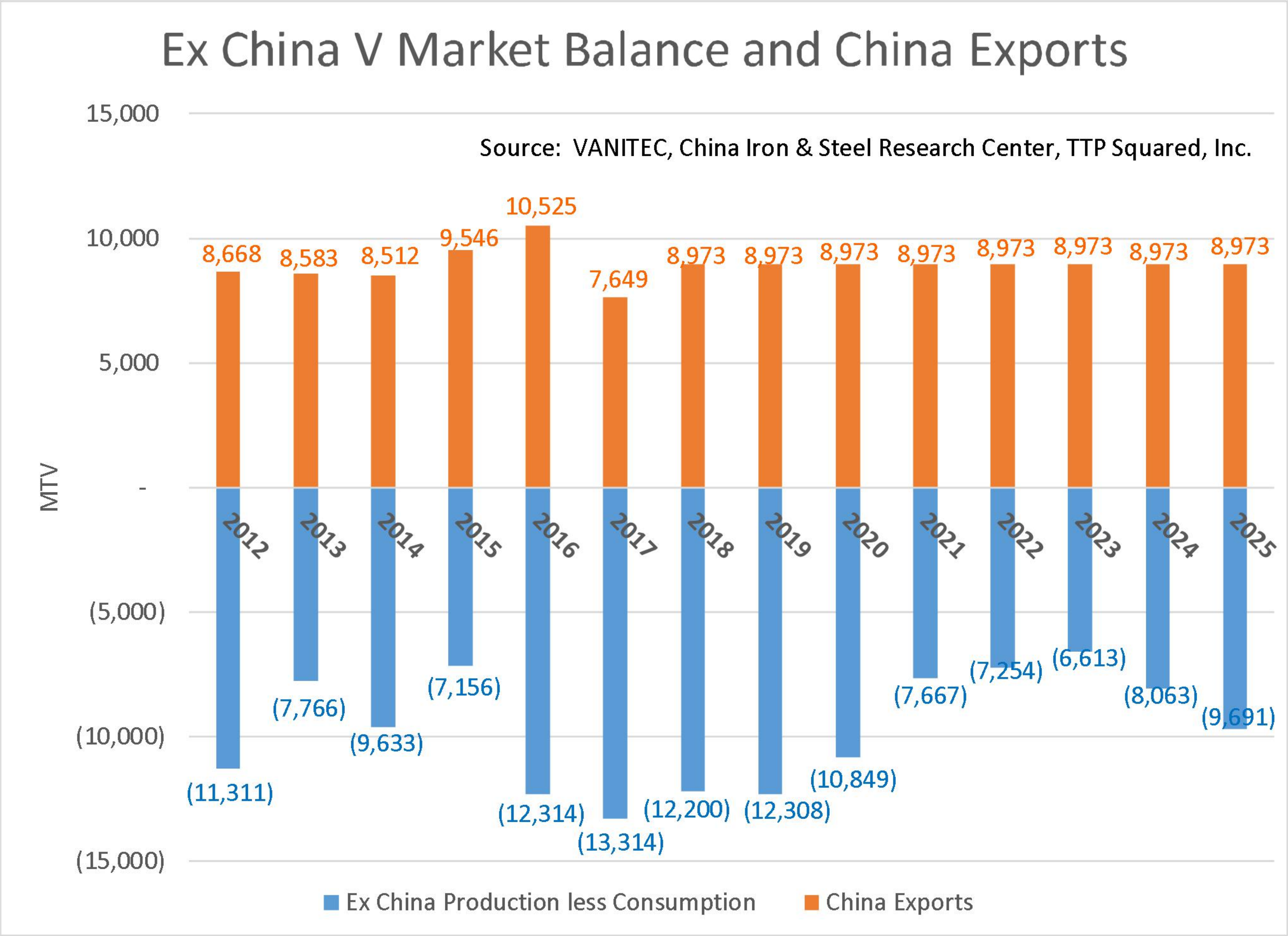

Ex China Cumulative Inventory Change
0
-2,000
-4,000
-6,000
-8,000
-10,000
-12,000
-14,000
-16,000
-18,000
Inventory Change (MTV)
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
$20.00
$18.00
$16.00
$14.00
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$-
V2O5 Price (in Warehouse Rotterdam US$/lb. V2O5)
Source: VANITEC, China Iron & Steel Research Center, TTP Squared, Inc.
Cumulative Inventory Change
V2O5 Price


Ex China V Market Balance and China Exports
Source: VANITEC, China Iron & Steel Research Center, TTP Squared, Inc.
15,000
10,000
5,000
-
(5,000)
(10,000)
(15,000)
MTV
8,668
8,583
8,512
9,546
10,525
7,649
8,973
8,973
8,973
8,973
8,973
8,973
8,973
8,973
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
(11,311)
(7,766)
(9,633)
(7,156)
(12,314)
(13,314)
(12,200)
(12,308)
(10,849)
(7,667)
(7,254)
(6,613)
(8,063)
(9,691)
Ex China Production less Consumption
China Exports

ex China Supply and Demand Balance

- Assuming no new sources of supply
  - We project the world ex China supply will continue to be less than ex China demand through 2020
  - Ex china vanadium inventories have decreased by about 11,000 MTV since the market bottomed out in December 2015
  - Inventories ex china will drop by a further 5,000 MTV from end of 2018 until the end of 2020
  - Beyond 2020 ex china inventories begin to recover until 2025 when inventories once again begin to be depleted
  - On a cumulative basis the deficit in total supply vs demand peaks at 15,000 MTV in 2020 before beginning to recede
- **Our projection for the future makes the assumption that Chinese vanadium exports will be constant at the 2018 level of roughly 9,000 MTV per year**
- **This projection does not include provision for any new production ex China**

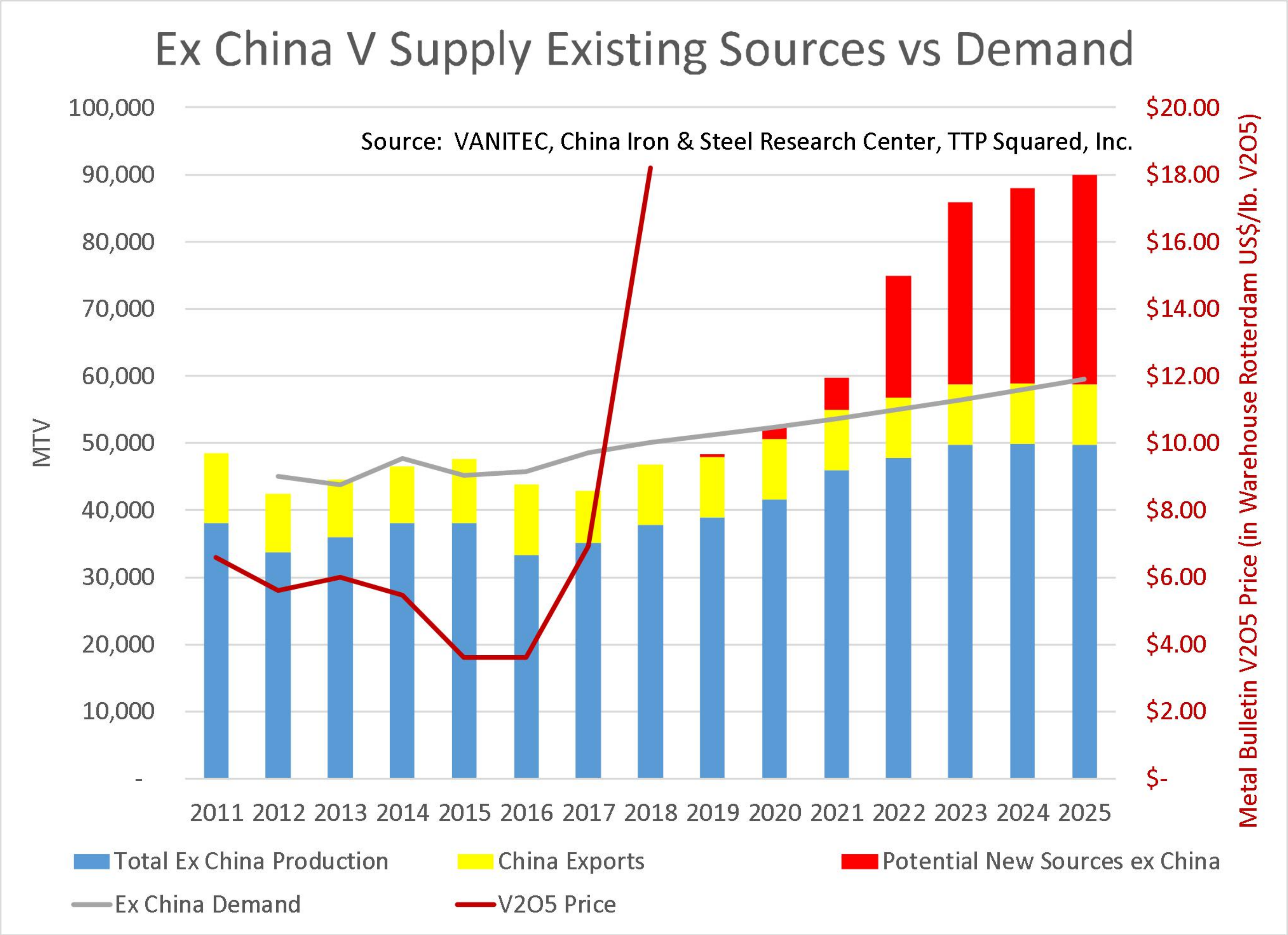
New Sources of Supply

Potential New Sources of Vanadium ex China

Company name	Domicile	website	stock exch+symb	Project name	Project location	Deposit type
American Lithium Corp.	Canada, Vancouver	www.americanlithiumcorp.com	TSX: LI	Extinction Ridge	USA, Nevada	sediment hosted
Blue Bird Mattery Metals Inc.	Canada, Vancouver	www.bluebirdbatterymetals.com	TSX: BATT	Canegrass	Western Australia	layered mafic intrusion
Critical Metals Ltd	Australia	www.criticalmetals.eu		Soidinvaara	Finland	magmatic, ilmenomagnetite
Delrey Metals Corp.	Canada, Vancouver	www.delreymetals.com	CSE: SPMT	Star and Porcher	Canada, BC	magmatic, ilmenomagnetite
Delrey Metals Corp.	Canada, Vancouver			Blackie and Peneece	Canada, BC	magmatic, mineralized gabbro
Energy Fuels Inc.	USA, Lakewood	www.energyfuels.com	TSX: EFR	White Mesa Mill	Colorado	V in tailings of uranium mill
First Vanadium Corp.	Canada, Vancouver	www.firstvanadium.com	TSX: FVAN	Carlin Vanadium	USA, Nevada	sediment hosted
Intermin Resources Ltd.	Australia, Nedlands	www.intermin.com.au	ASX: IRC	Richmond	Australia, Queensland	sediment hosted, V+Mo
King River Resources Ltd	Australia, Perth	www.kingriverresources.com.au	ASX: KRR	Speewah	Western Australia	magmatic, ilmenomagnetite
Maxtech Ventures Inc.	Canada, Vancouver	www.maxtech-ventures.com	CST: MVT	exploration claims	Brazil, Bahia	magmatic
Maxtech Ventures Inc.				Lac Patu	Canada, Quebec	sediment hosted
Multicom Resources Ltd.	Australia, Brisbane	www.mcres.com.au/	private	Saint Elmo	Australia, Queensland	sediment hosted, U+V
Neometals Ltd.	Australia, Perth	www.neometals.com.au	ASX: NMT	Barrambie	Western Australia	magmatic, ilmenomagnetite
New Energy Minerals	Australia, Perth	www.newenergyminerals.com.au	ASX: NXE	Caula	Mozambique	Graphite schists
Primary Energy Metals Inc.	Canada, Vancouver	www.primaryenergymetals.com	CSE: PRIM	Nirvana-Polar Mesa	USA, Colorado	sediment hosted, U+V
Primary Energy Metals Inc.	Canada, Vancouver			Odin-Altair	Spain, Badagoz	sediment hosted
Pursuit Minerals Ltd.	Australia, Brisbane	www.pursuitminerals.com	ASX: PUR	Airijoki	Sweden	magmatic, ilmenomagnetite
Pursuit Minerals Ltd.				Koitelainen	Finland	magmatic, ilmenomagnetite
Pursuit Minerals Ltd.				Karhukupukka	Finland	magmatic, ilmenomagnetite
Queensland Energy and Mineral	Australia, Perth	www.qldem.com.au	ASX: QEM	Julia Creek	Australia, Queensland	Oil shales
Redzone Resources Ltd.	Canada, Vancouver	www.redzoneresources.ca	TSX: REZ	Wells	Canada, BC	sediment hosted
Regency Mines Plc.	Great Brittain, London	www.regency-mines.com	AIM: RGM	Yukon	USA	sediment hosted
Searchlite Resources	Canada, Vancouver	www.searchlightresources.com/	TSX: SRCH	Duddridge Lake	Canada, BC	sediment hosted, U+V+Co
Spearmint Resources Inc.	Canada, Vancouver	www.spearmintresources.ca	CSE: DLRY	Chibougamau	Canada, BC	magmatic, ilmenomagnetite
Spey Resources Corp.	Canada, Vancouver	www.speyresources.ca	CSE: SPEY	Uravan	USA, Utah	sediment hosted, U+V
Surefire Resources NL	Australia, Perth	www.surefireresources.com.au	ASX: SRN	Unaly Hill	Western Australia	magmatic, ilmenomagnetite
Tando Resources	Australia, Perth	www.tandoresources.com.au	ASX: TNO	SPD	South Africa	magmatic, ilmenomagnetite
Tarku Resources Ltd.	Canada, Saskatoon	www.tarkuresources.com	TSX: TKU	Lac-Fabien	Canada, Quebec	magmatic, ilmenomagnetite
Technology Metals Ltd.	Australia, Perth	www.tmtlimited.com.au	ASX: TMT	Gabanintha	Western Australia	magmatic, mineralized gabbro
United Battery Metals Corp.	Canada,Vancouver	www.ubmetals.com	OTCBB: UBMCF	Wray Mesa	USA, Colorado	sediment hosted, U+V
Vanadian Energy Corp.	Canada, Vancouver	www.vanadianenergy.com	TSX: VEC	Huzyk Creek	Canada, Manitoba	sediment hosted
Vanadium One Energy Corp.	Canada, Toronto	www.vanadiumone.com	TMX: VONE	Mount Sorcier	Canada, Quebec	magmatic, ilemenomagnetite
Venus Metals Corporation Ltd	Australia, Perth	www.venusmetals.com.au	ASX: VMC	Youanmi V-Oxide	Western Australia	magmatic, oxidized gabbro
Westwater Resources	USA, Centennial	www.westwaterresources.net	NASDAQ: wwr	Coosa Graphite	USA, Alabama	sediment hosted

Potential New Sources of Supply of V

- Outside of China there are more than 80 potential new vanadium projects being promoted.
- Historically the time line for construction of a new primary vanadium mine and mill is 5 years from receipt of construction financing until first production
- Historically the time line from first production to full capacity in a new primary vanadium mine and mill is 18 months
- There are several secondary vanadium projects being promoted today that can have a shorter time to market than primary vanadium mining projects
- There are few potential new projects that have any significant funding in place today


Ex China V Supply Existing Sources vs Demand
Source: VANITEC, China Iron & Steel Research Center, TTP Squared, Inc.
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
-
MTV
$20.00
$18.00
$16.00
$14.00
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$-
Metal Bulletin V2O5 Price (in Warehouse Rotterdam US$/lb. V2O5)
2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025
Total Ex China Production
China Exports
Potential New Sources ex China
Ex China Demand
V2O5 Price

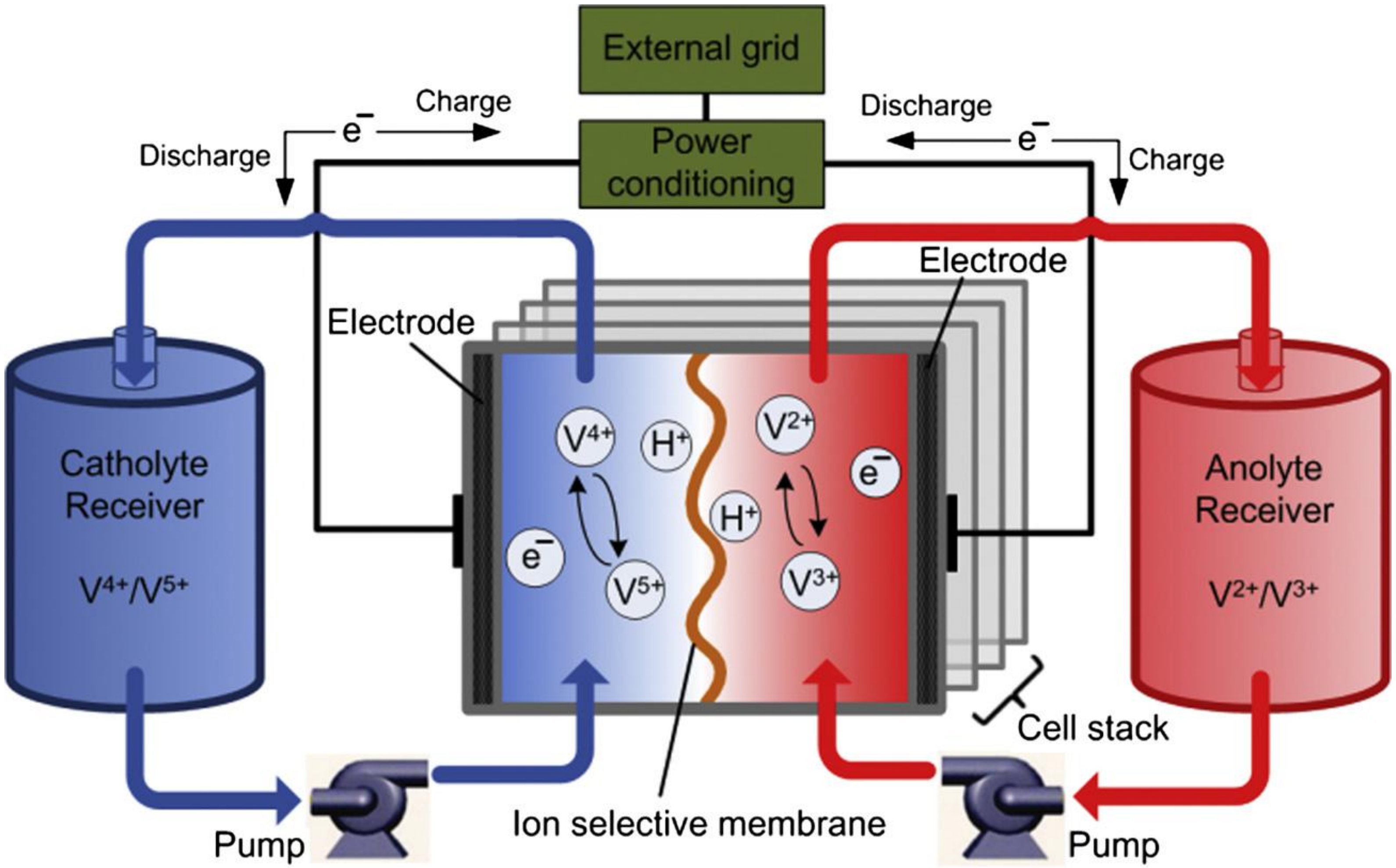
Summary

- Vanadium consumption today is driven primarily by use in the steel industry. Changing steel production volumes and changing specific vanadium consumption rates are the major variables impacts vanadium consumption
- Vanadium production is limited by the availability of economically viable raw materials. Currently there is very little idle capacity outside of China that can contribute to growth in vanadium production in the near term
- Vanadium consumption outside of China has outstripped production for the past 8 years by an average of 10,500 MTV per year.
- Chinese exports have averaged 9,000 MTV/yr. over the past 8 years.

Summary

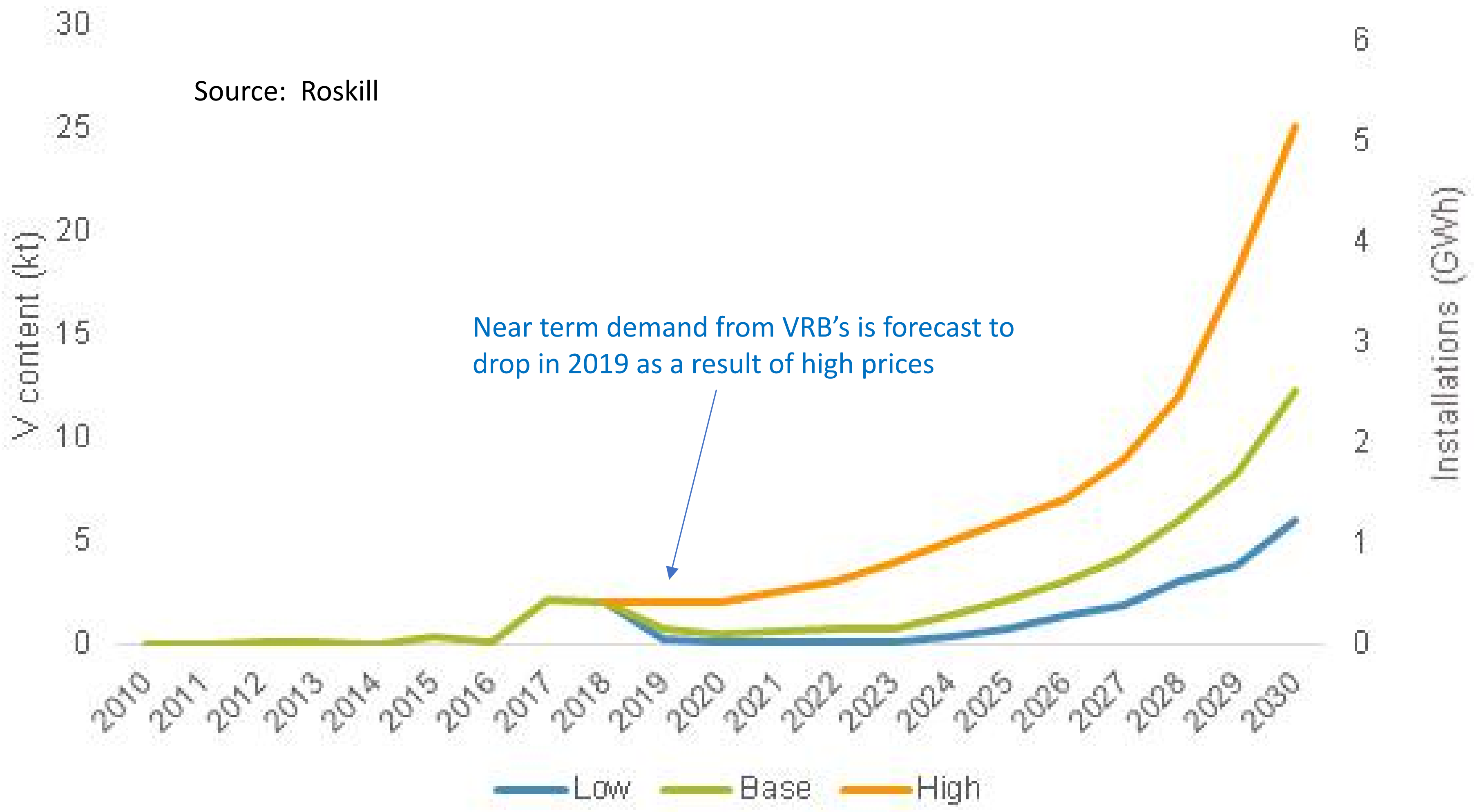
- Total vanadium supply ex China is anticipated to be less than ex China demand through 2019.
- Growth in supply from existing sources combined with potential new sources and ongoing Chinese exports could result in a balanced market ex China in 2020.
- Longer term potential new vanadium projects ex China could result in significant oversupply ex China from 2022 onward without any new sources of demand
- The availability and price of Chinese vanadium exports will be a major driver to the international vanadium market situation over the next several years

Vanadium Redox Flow Batteries



Structure of a vanadium redox flow battery

Global Vanadium Demand in VRB's



Vanadium Redox Flow Batteries

- The high vanadium price is projected to result in a decrease in deployment of vanadium in VRB's in 2019 relative to 2018. it is difficult to forecast future demand in this application due to the price sensitivity to vanadium.
- Today competition for VRB's is primarily lithium ion systems. Li ion is suitable for some grid level storage applications (black start, frequency modulation, voltage regulation and control, etc.) and other short duration applications.
- VRB's are ideally suited for long duration applications (time shifting, peak shaving and load leveling).

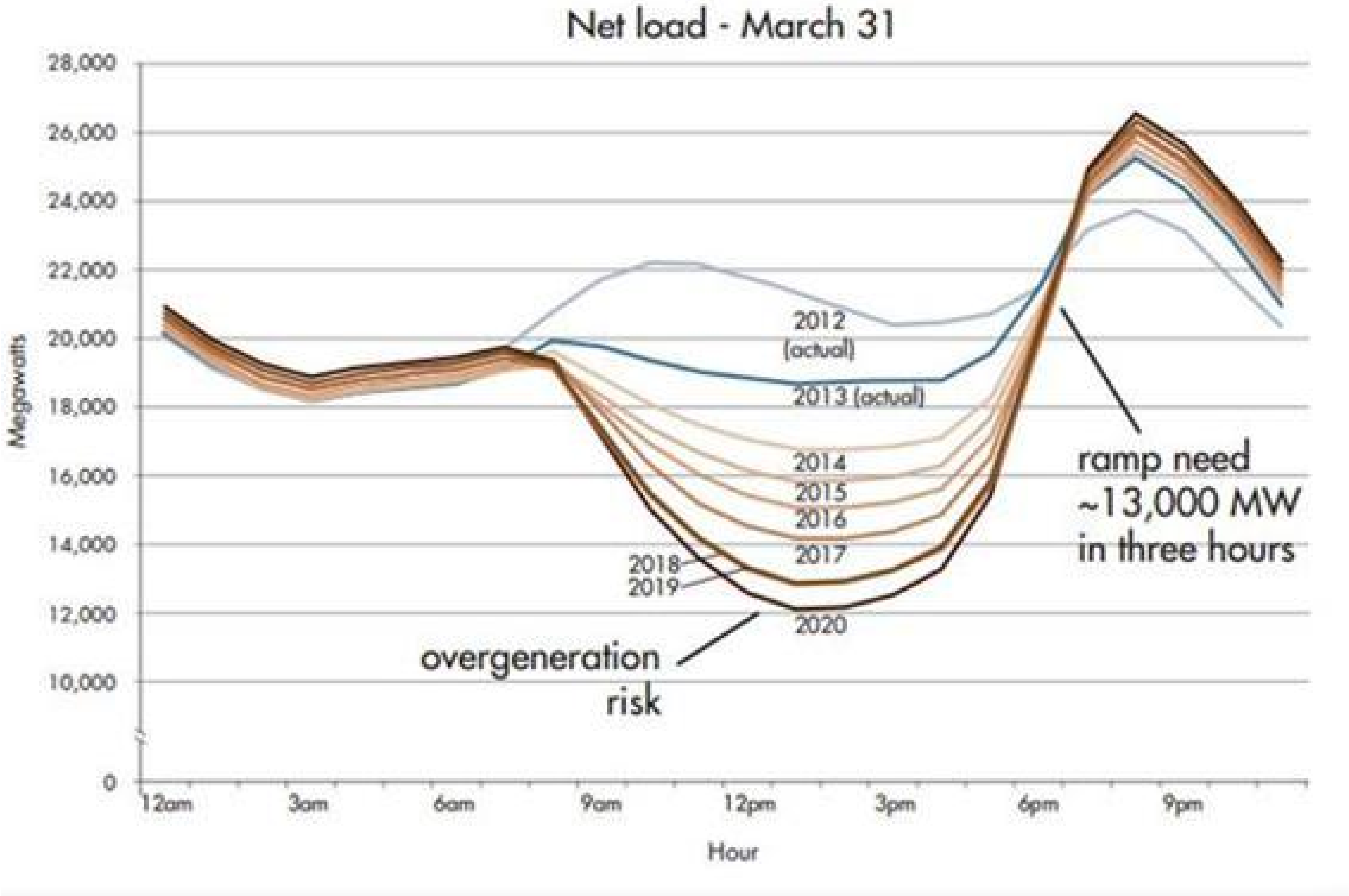
Vanadium Redox Flow Batteries

- In recent times the market for grid level energy storage has been mostly related to short duration applications. In this market Li ion can compete with VRB's and given the fact that Li ion technology is more mature than VRB technology the capital cost of VRB systems has been more competitive than VRB's
- Assuming historically normal vanadium prices, today the capital cost of VRB's approach the capital cost of Li ion systems for grid level applications. Looking at the long term cost of the asset one can make an argument that VRB's would be less expensive today than Li ion systems if vanadium prices were in historically normal ranges

Vanadium Redox Flow Batteries

- The cost of producing electricity from solar panels is arguably today the cheapest source of new electrical power. As a result we are seeing massive growth in solar power production in many regions of the world.
- Solar power can only be produced when the sun is shining. However the demand of electricity varies significantly during the day, and the peak demand occurs when production of solar power is near a low point in the daily cycle.
- Today in California peak production of solar power occurs approx. 2:00 PM while peak demand occurs approx. 9:00 PM

California Duck Curve



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Vanadium Redox Flow Batteries

- The massive growth in solar power production is resulting in a growing need for long duration storage technologies to support load leveling and peak shaving applications.
- The economic benefit of technologies that can allow solar power produced in the middle of the day to be delivered to the grid in the evening peak demand time is massive
  - Elimination of peaking plants which typically have very high operating and maintenance costs
  - Leveling load on the grid resulting in lower operating costs and better efficiencies
- Today, and in the future, energy storage technologies will win market share based on the value the asset delivers to the grid. Growing solar power production creates an environment where VRB's may be the best choice and Li ion systems are not capable of meeting critical long duration applications

Summary

- Vanadium redox flow batteries are reaching a state of maturity where they are cost competitive at normal vanadium market prices with other technologies and offer performance advantages in many applications
- High vanadium prices have negatively impacted the deployment of vanadium in flow battery applications
- It is anticipated that when vanadium markets come back into supply/demand balance and prices trend towards historical norms demand from flow battery applications will grow – in essence the flow battery market could put a floor on vanadium prices at historical levels going forward

New Applications for Vanadium

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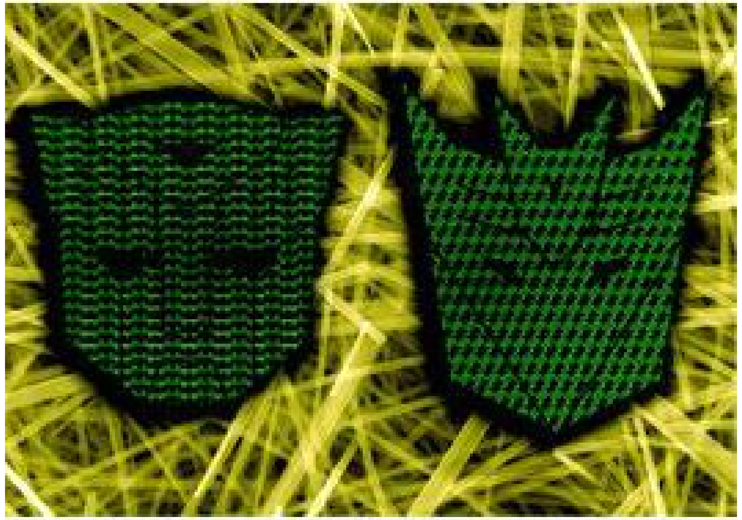
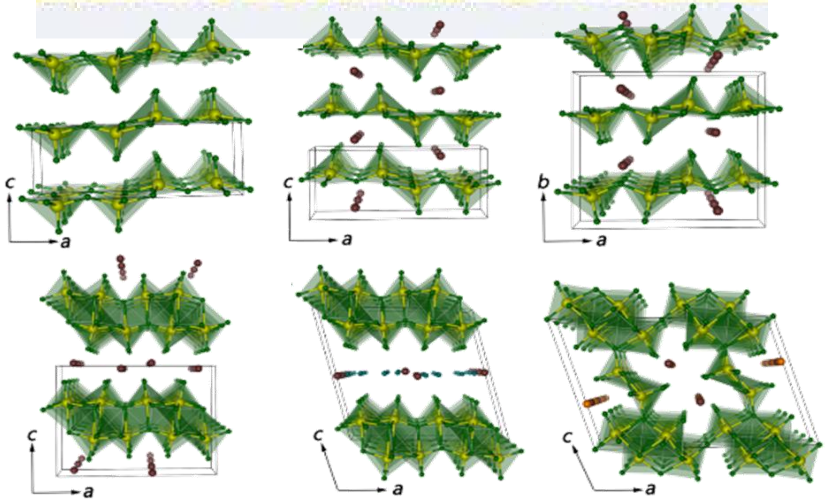
TRANSFORMERS: THE UNDERAPPRECIATED PROPERTIES OF vanadium oxides

- Variable valence -1 to +5
- Tetrahedral, square pyramidal, and octahedral coordination environments
- d-orbitals not too narrow and not too broad
- Wide range of open ordered and disordered defect structures, non-stoichiometry, and crystallographic shear
- **Phase transitions!**





P. M. Marley, G. A. Horrocks, K. E. Pelcher, and S. Banerjee, *Chemical Communications* **2015**, *51*, 5181-5198
L. Whittaker, C. J. Patridge, and S. Banerjee, *J. Phys. Chem. Lett*. **2011**, 2, 745-758

Where does vanadium go NEXT?

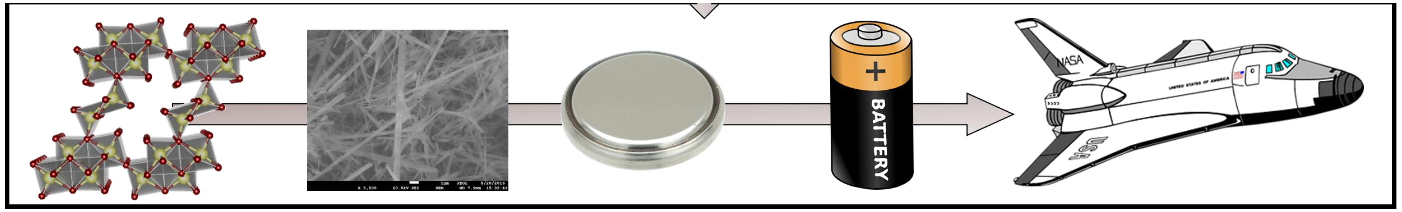
CASE STUDIES IN ENERGY APPLICATIONS OF VANADIUM:

THERMOCHROMIC FENESTRATION (SMART WINDOWS!)

INTERCALATION BATTERIES

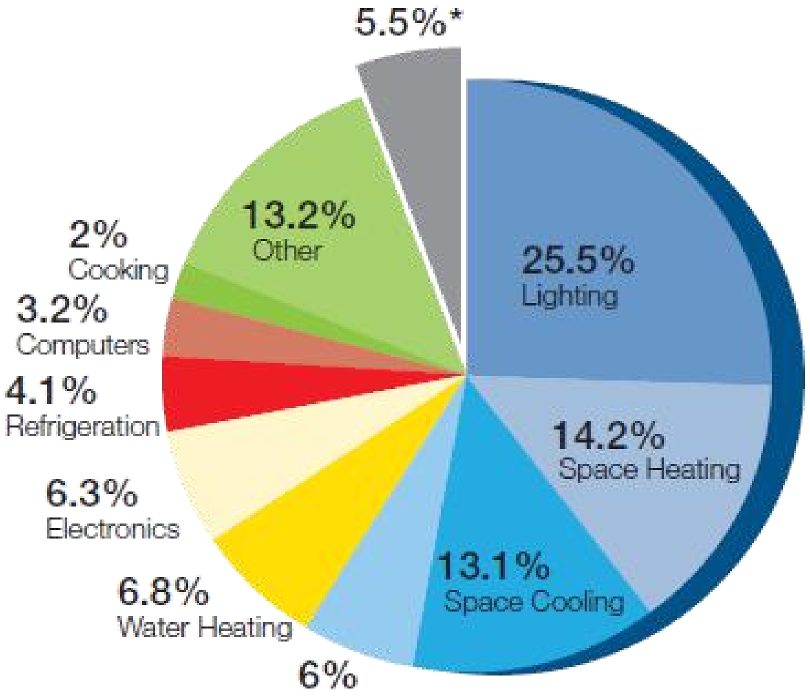
ENERGY-EFFICIENT COMPUTING

ARTIFICIAL LEAF FOR WATER SPLITTING



Thermochromic FENESTRATION (SMART WINDOWS!)

- 40% of energy consumed in Mumbai, India goes toward space cooling
- China added 50M home air-conditioning units in 2010
- By 2050 27% of all global warming will be due to coolant gases



Breakdown of building energy consumption

- $15B
- 140M metric tons of CO_2

US Department of Energy, Energy Efficiency Trends in Residential and Commercial Buildings, Washington DC2008

LIGHT WITHOUT HEAT

Dynamic switching of optical properties as a result of phase transitions

Under cold ambient conditions, the breadth of the solar spectrum is transmitted.

- warming the interior

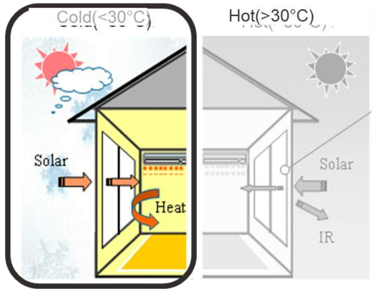


Image from AIST Japan

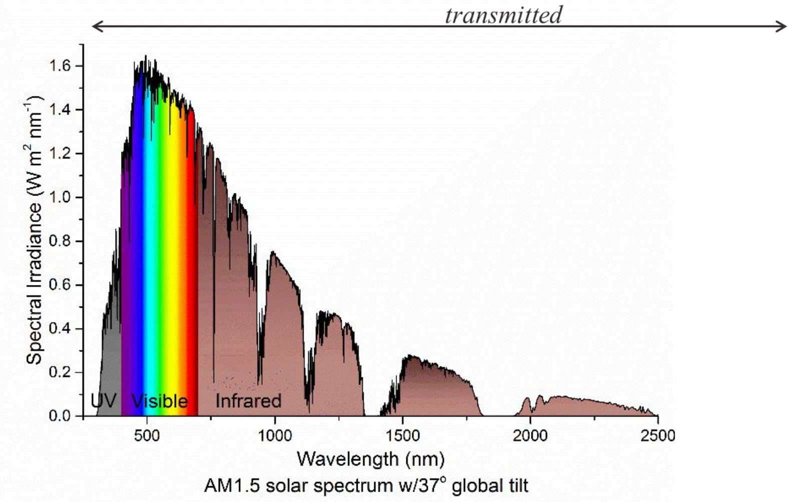
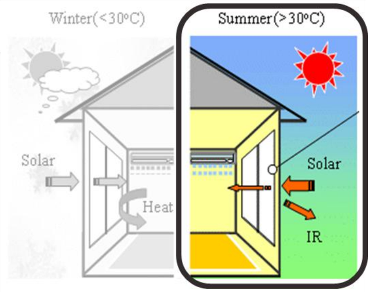


Image from AIST Japan

Under hot ambient conditions, infrared radiation is reflected.

- **Reducing solar heat gain and space cooling**



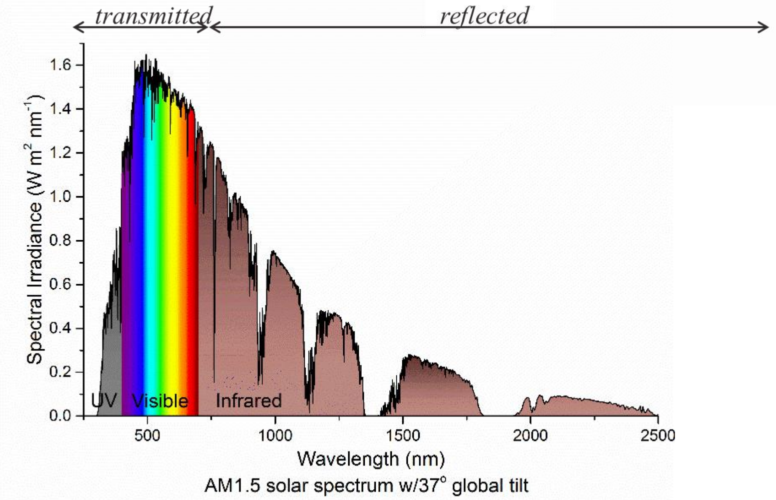
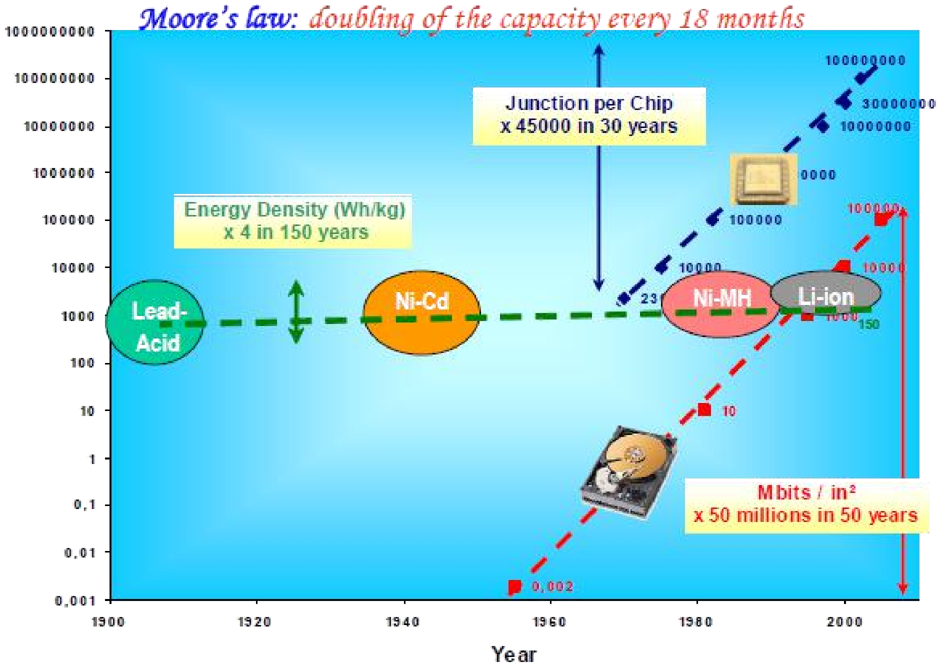
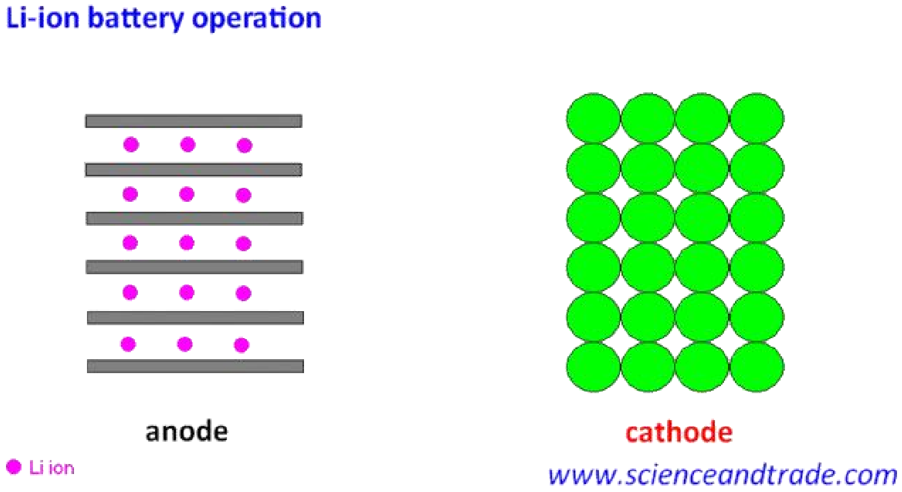


Image from AIST Japan

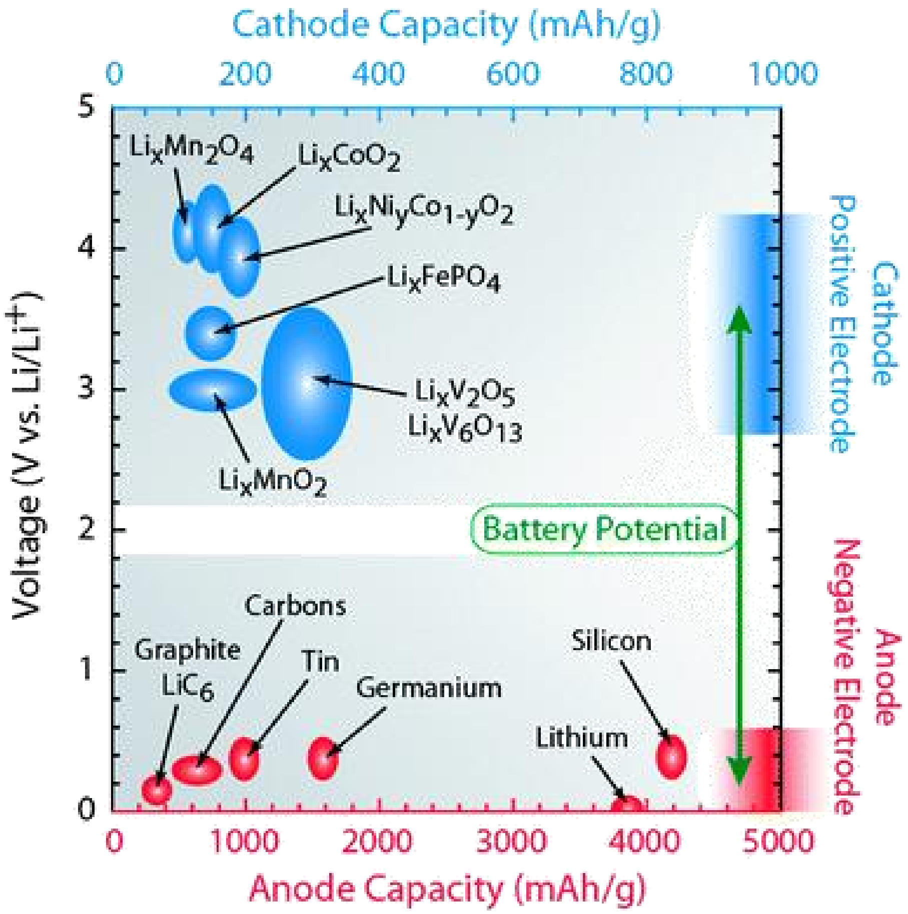
Issues facing intercalation Batteries: Life beyond Li-ION BATTERIES

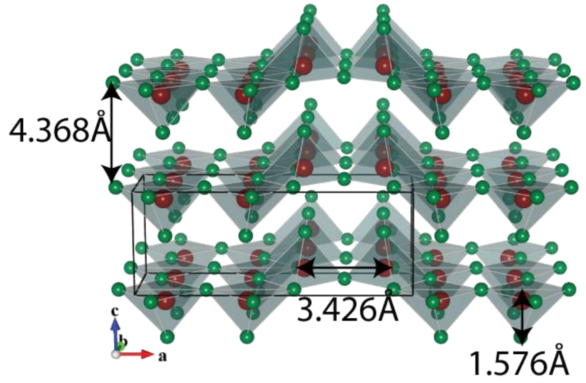




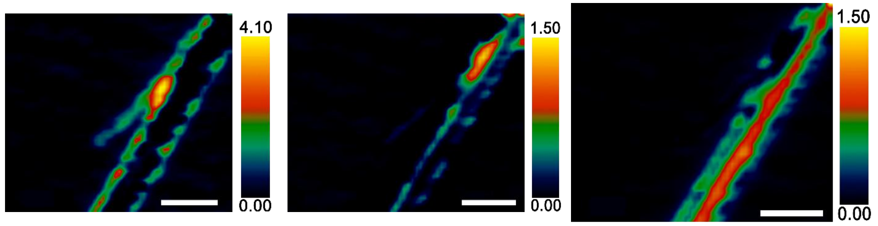
- ❑ Safety, safety, safety!
- ❑ Materials criticality! Is there enough lithium?
- ❑ A transformational breakthrough needed in energy and power densities?

Vanadium oxides for Intercalation Batteries



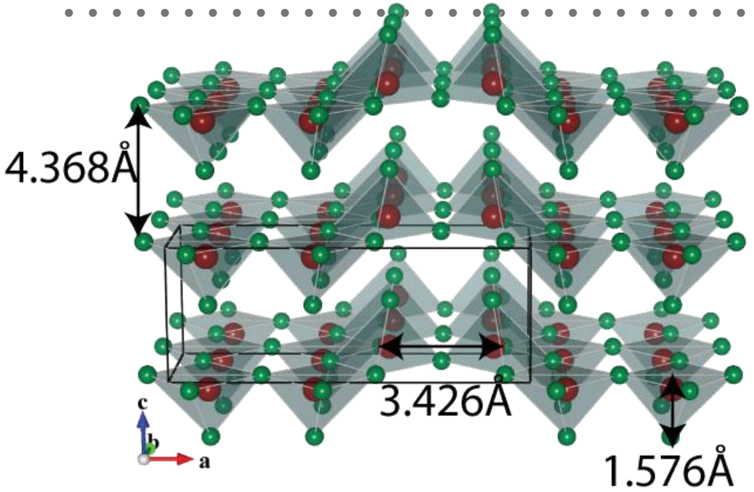


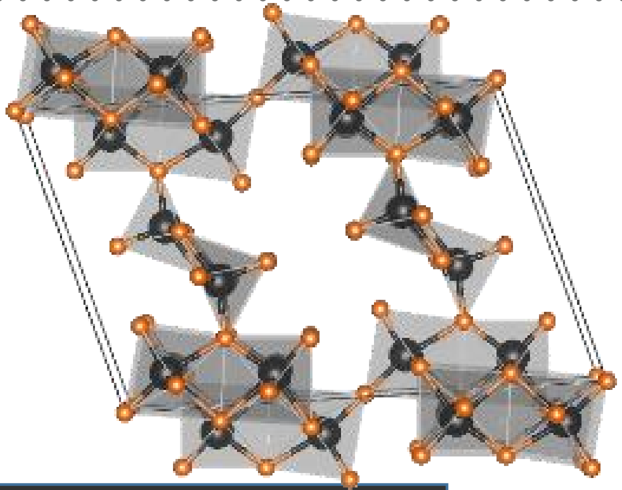
Layered 2D framework with room for Li-ions-
But Li-ions run into bottle-necks



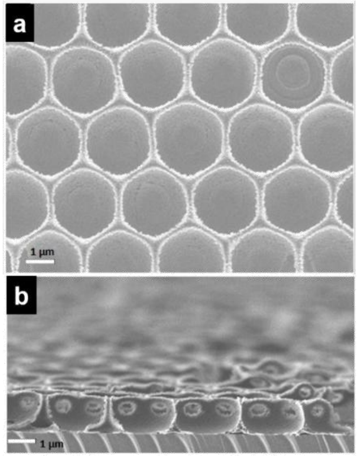
De Jesus, L. R.; Horrocks, G. A.; Liang, Y.; Parija, A.; et al. Nat. Commun. 2016, 7, 1–9.
Bhatt, M. D.; O'Dwyer, C. **Phys. Chem. Chem. Phys.**, 2015, **17**, 4799-4844.

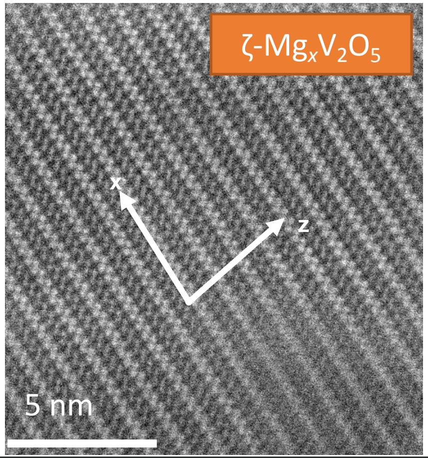
A new phase of V_2O_5: a path to viability for Mg-ion batteries





First new V_2O_5 structure in over 100 years





- High voltage, high capacity, and high reversibility
- Pathway to safe, earth-abundant, and large area batteries made from vanadium

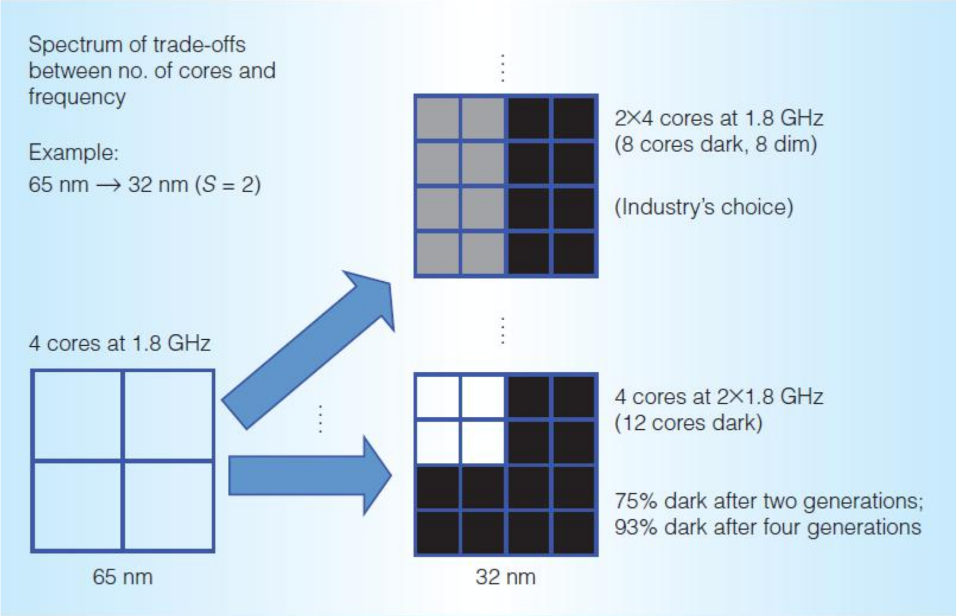
VANITEC
TRANSFORMING POSSIBILITIES

Chalker, C. J., An, H., Zavala, J., Parija, A., Banerjee, S.., LutkenhausJ. L., Batteas, J. D. Langmuir, 2017, 733 . 5975-5981

the "age of dark silicon"

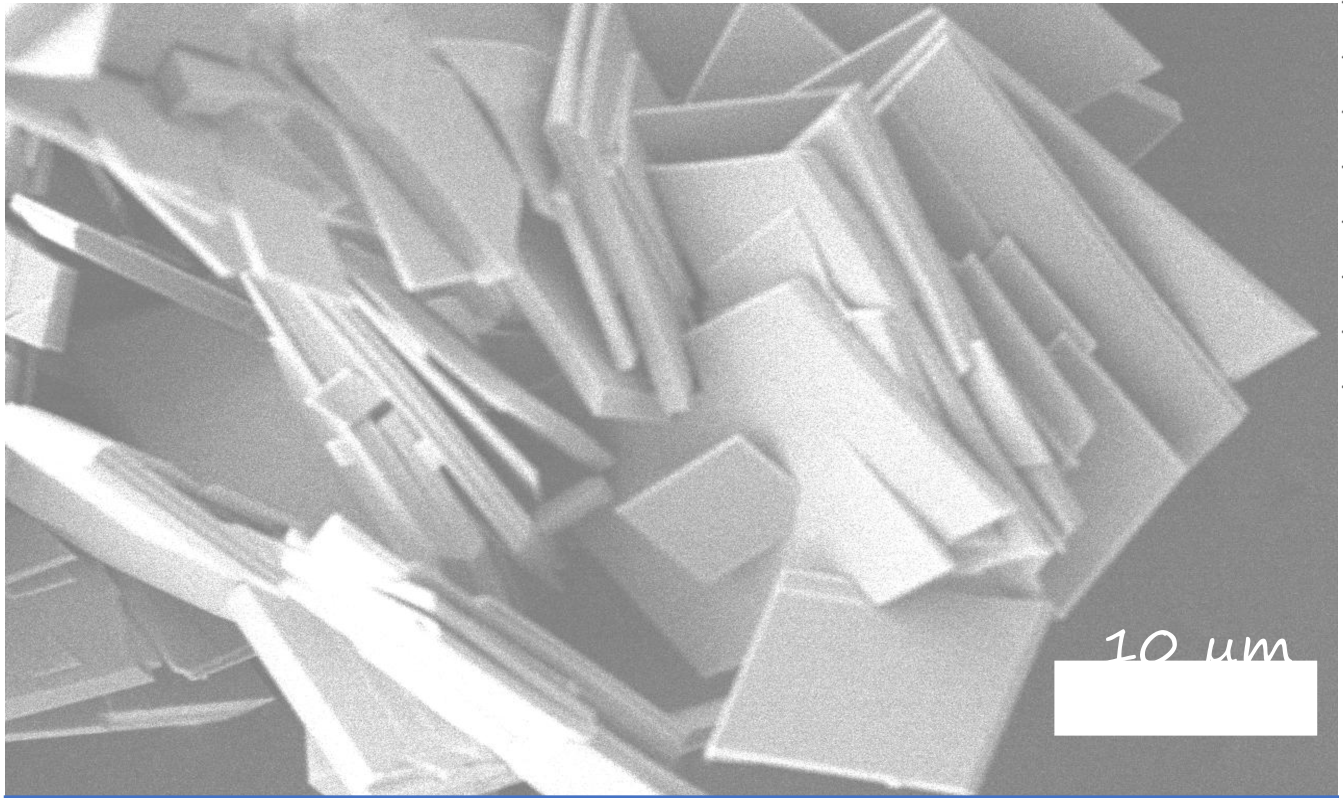
Table 1. Dennard vs. post-Dennard (leakage-limited) scaling.[1] In contrast to Dennard scaling,[5] which held until 2005, under the post-Dennard regime, the total chip utilization for a fixed power budget drops by S^2 with each process generation. The result is an exponential increase in dark silicon for a fixed-sized chip under a fixed area budget.

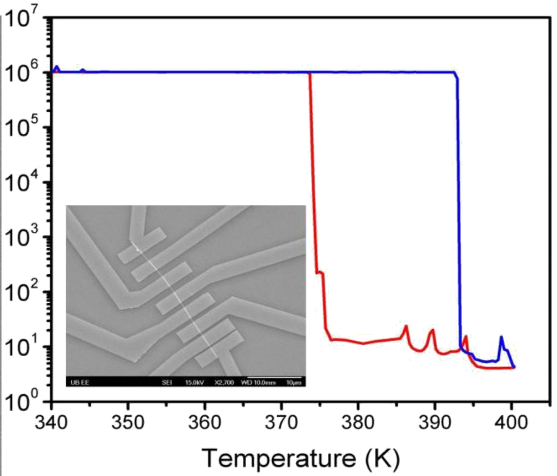
Transistor property	Dennard	Post-Dennard
Δ Quantity	S^2	S^2
Δ Frequency	S	S
Δ Capacitance	$1/S$	$1/S$
V_{DD}^2	$1/S^2$	1
$\Rightarrow \Delta$ Power $= \Delta$ $QFCV^2$	1	S^2
$\Rightarrow \Delta$ Utilization = 1/Power	1	$1/S^2$

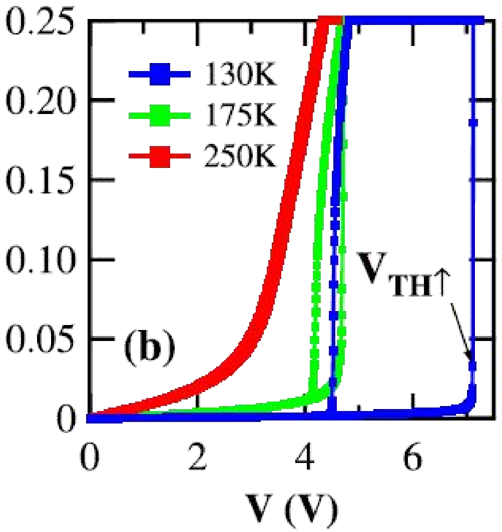


- ❑ Modern microprocessors are energy guzzling because power consumption does not scale with transistor dimensions.
- ❑ Cell-phones and personal electronics run hot!
- ❑ Major roadblock to meeting future high-performance computing needs.

Vanadium in the "age of dark silicon"



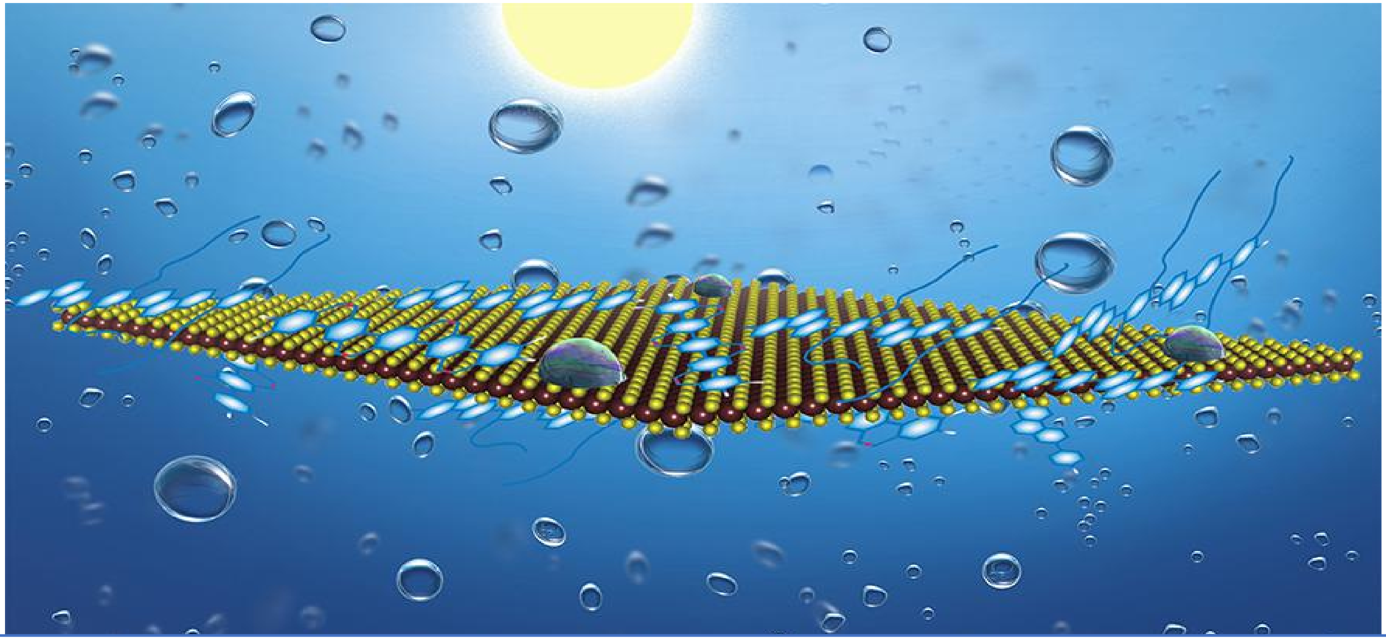




- ❑ New "Mott" switching mechanisms and memory that are massively scalable in terms of power consumption

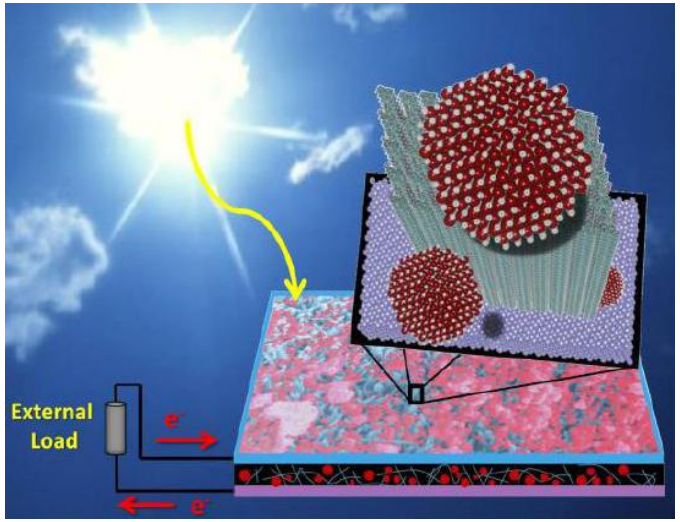
C. J. Patridge, C. Jaye, H. Zhang, A. C. Marschilok, D. A. Fischer, E. S. Takeuchi, and S. Banerjee, *Inorg. Chem.* 2009, *48*, 3145-3152.
C. J. Patridge, T.-L. Wu, G. Sambandamurthy, and S. Banerjee, *Chem. Commun.* 2011, *47*, 4484-4486.

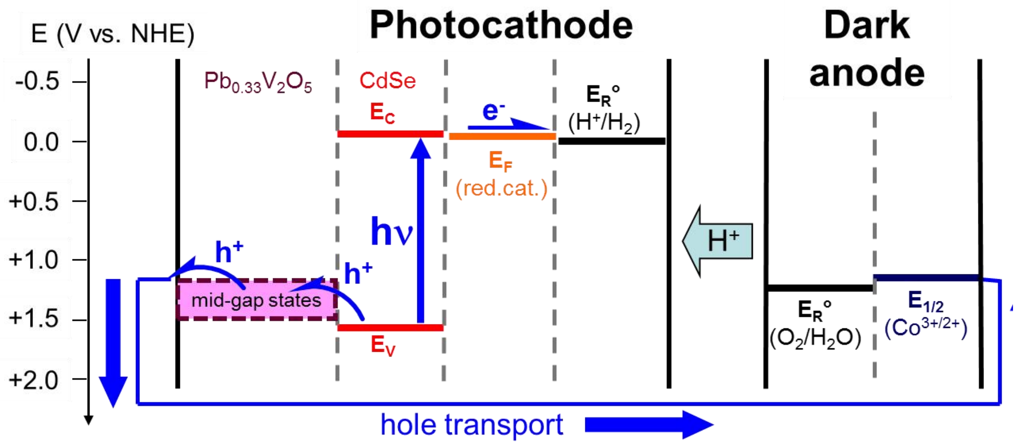
Splitting water with vanadium oxides to generate solar fuels



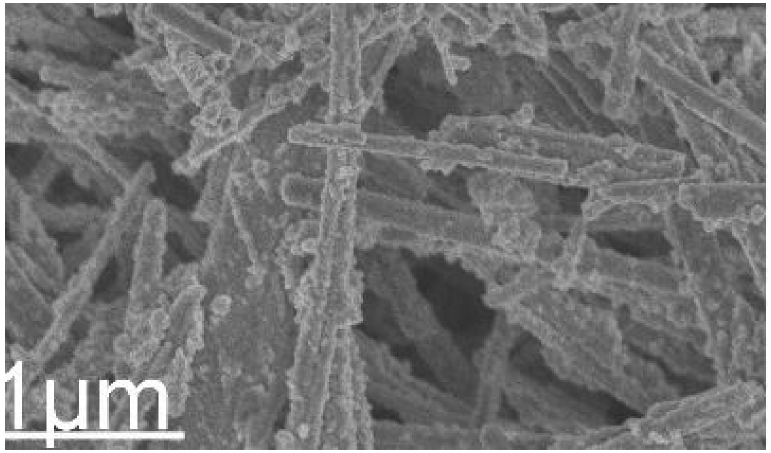
- ❑ Hydrogen is an energy dense fuel that is combusted releasing water as the only by-product
- ❑ Splitting water using sunlight –mimicking a leaf – to generate hydrogen would provide an endless fuel source
- ❑ *Oxidation of water is a huge challenge—most catalysts are destroyed rapidly*

Splitting water with vanadium oxide to generate solar fuels





- Miniature photosynthetic factories!
- Vanadium oxides can be tuned to introduce specific electronic states that can be used to oxidize water.
- Best-in-class performers that are building blocks for solar water electrolyzers.



VANITEC
TRANSFORMING POSSIBILITIES

Pelcher, K. E.; Milleville, C. C.; Wangoh, L.; Chauhan, S.; Crawley, M. R.; Marley, P. M.; Piper, L. F. J.; Watson, D. F.; Banerjee, S. Chem. Mater. 2015,27, 2468-2479.

Summary

- Vanadium will continue to support the efficient development of infrastructure required for economic opportunity in the developing world via the use of high strength low alloy vanadium steels
- Vanadium flow batteries could become a critical part of the global electrical grid supporting the ongoing deployment of renewable energy sources and microgrids.
- There are numerous potential new applications for vanadium in critical roles that are important in terms of impacting the global carbon footprint of human society