Overview of Gridscale Rampable Intermittent Dispatchable Storage (GRIDS) Program

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Advanced Research Projects Agency – Energy

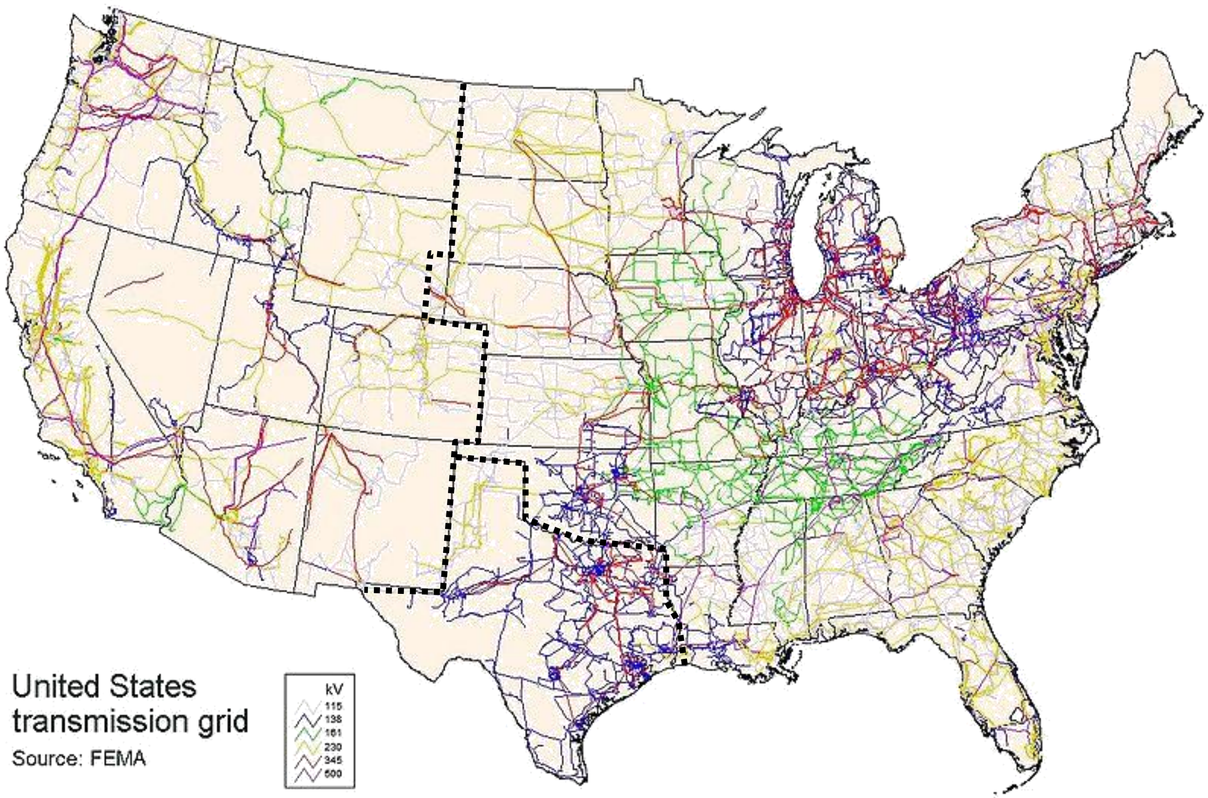
September 12, 2011

US Power Grid: World Largest Supply Chain With No Warehouse

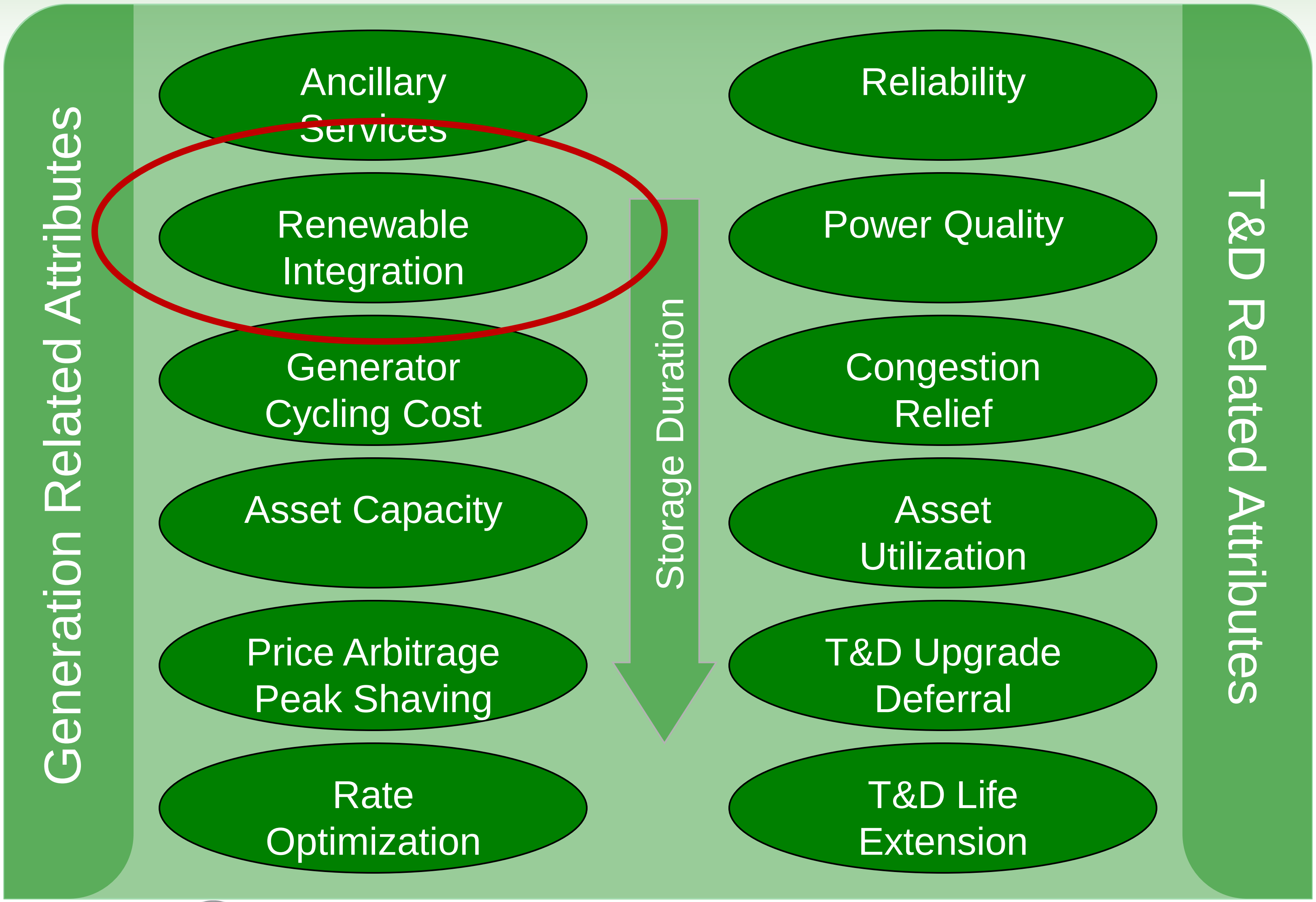
Electric Grid: Premier Achievement of 20th Century [NAE]

Harness Renewable Power: #1 Grid Challenge for 21st Century

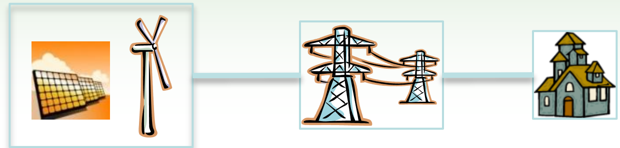
Storage Separates Electric Generation and Load in Space and Time



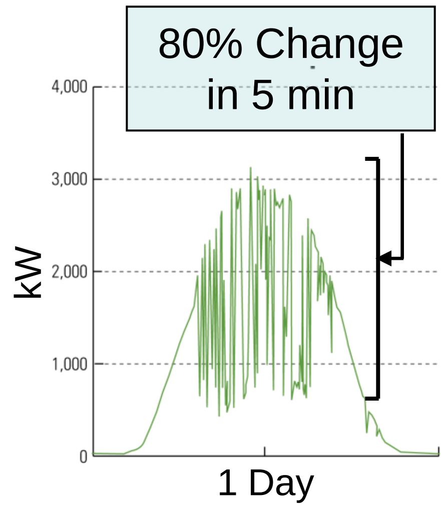
Electric Energy Storage Applications



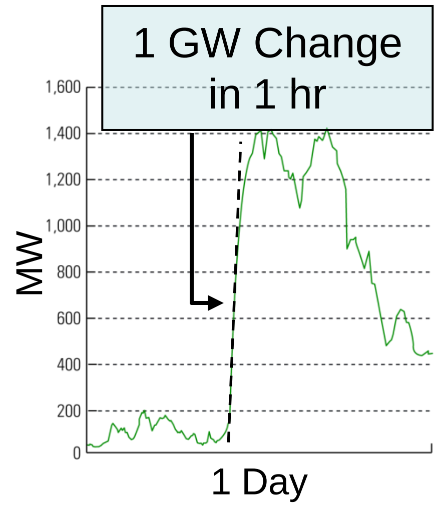
Storage For Firming Renewables



Solar PV in AZ (TEP)



Wind in OR (BPA)



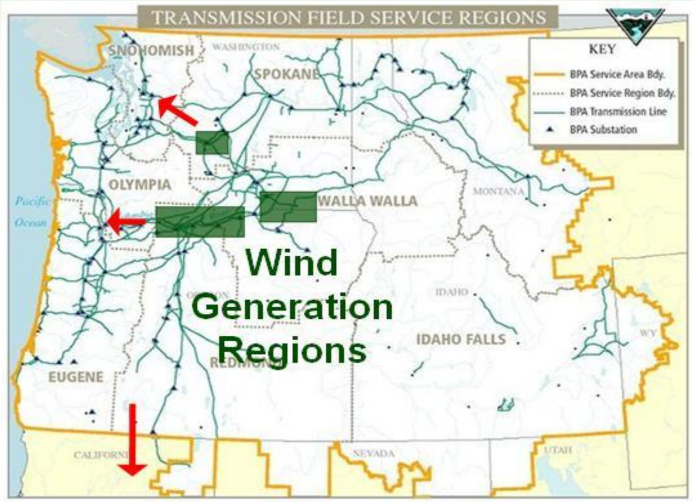
Problem:
Minutes-to-Hours Changes in Power

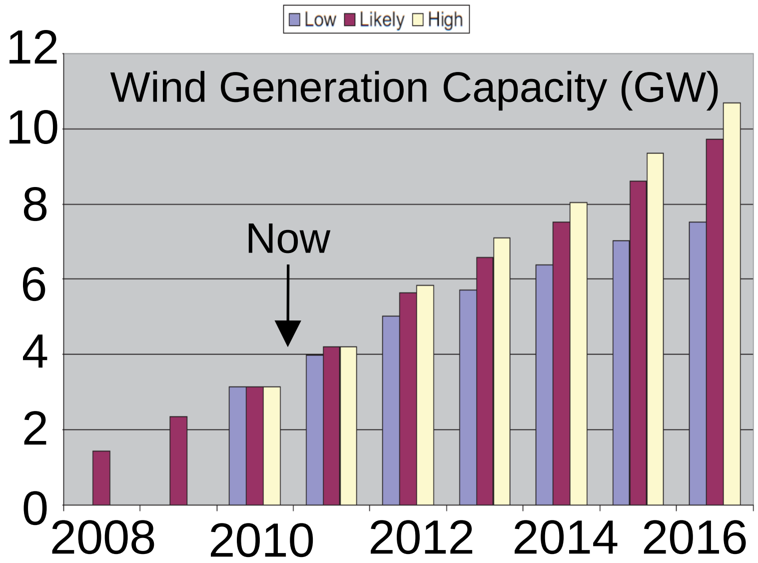
Need: Grid Storage that is Dispatchable and Rampable
ARPA-E: Energy Storage to Enable High Penetration of Renewables

High Renewable Generation Integration

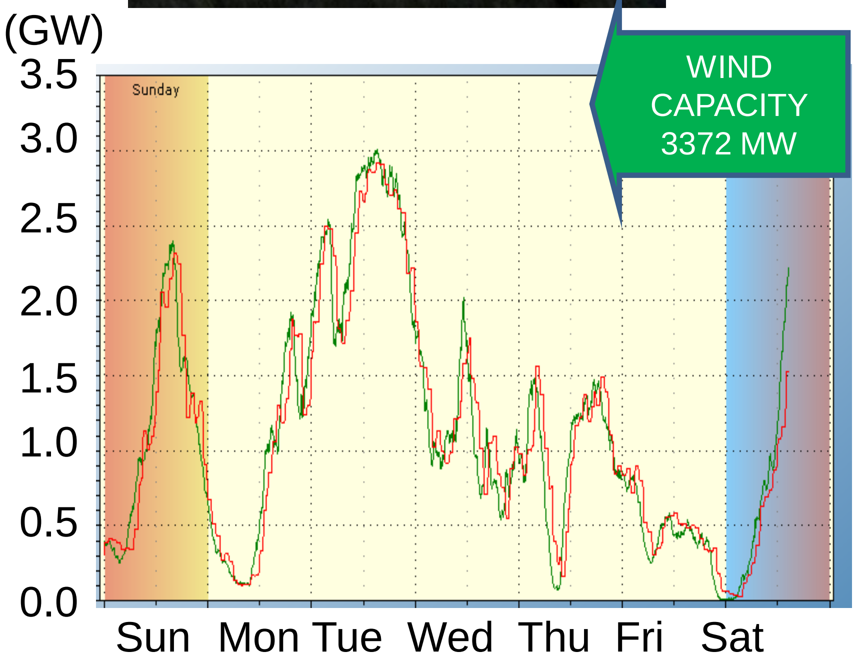
Challenge is a Grid Problem, not a Generator Problem

- Larger Balancing Authority
- Increase Transmission Capacity
- Improved Situational Awareness
  - Real Time Knowledge
  - Improved Weather Models
  - Generation Protocols
- New Storage Technologies
- Or More Spinning Reserves

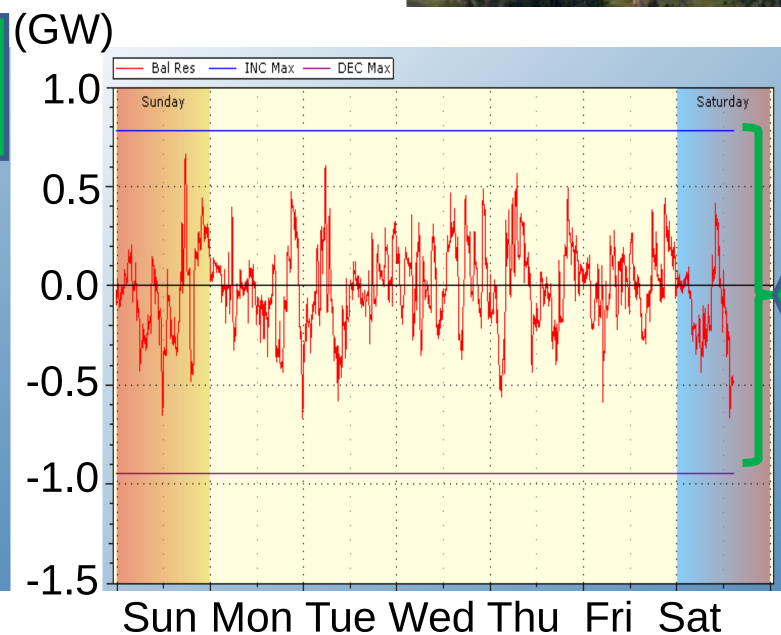




Balancing Reserves Firming Wind Generation for High Renewable Penetration on Power Grid



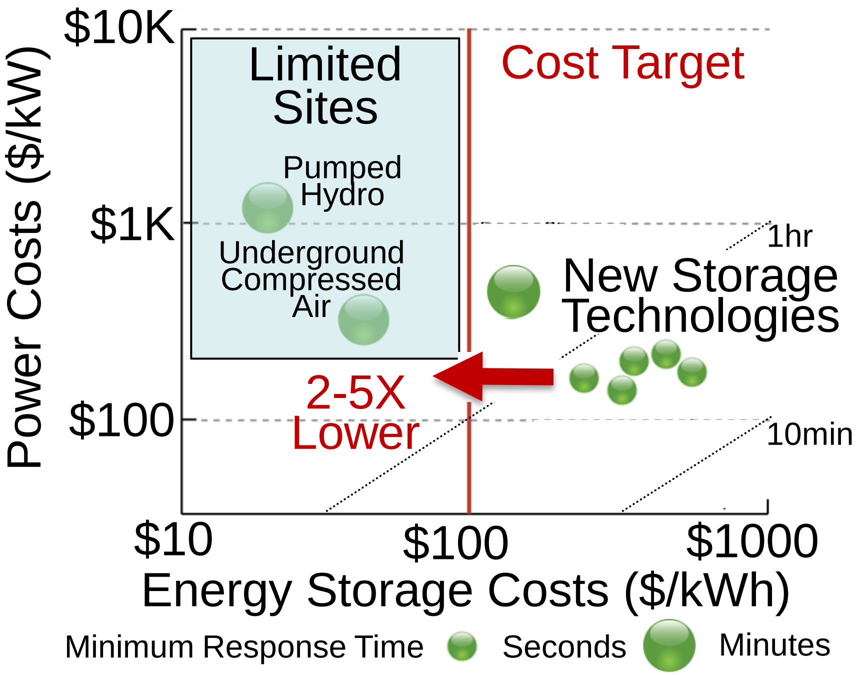
WIND CAPACITY 3372 MW



HYDROPOWER RANGE 1600-2000MW

System Challenge: Efficient Energy Storage at Minutes to Hours Duration to Firm Ramping Balance

Grid-scale Rampable Intermittent Dispatachable Storage (GRIDS) Metrics



Economics of Hydro / Deploy Anywhere

Technology Agnostic:
Chemical, Mechanical, Electromagnetic

Connect Across Industry for Handoffs

Focus: Transformational approaches to energy storage to enable low cost

New Technology Need: Cost-Effective Energy Storage Solutions

Portfolio of Projects

UNIVERSITY/ LAB

USC — University of Southern California: Rechargeable Fe-Air Battery

Berkeley Lab: Advanced Flow Battery

CUNY — The City University of New York: Rechargeable $Zn\text{-}MnO_2$ Battery

SMALL BUSINESS

Primus Power (Smart Grid Storage): New Flow Battery Electrode

Fluidic Energy: High Power Metal-air Storage

Proton Energy Systems: Neutral Water Fuel Cell

Beacon Power: Long Duration Flywheel

General Compression (expanding clean power): Fuel-Free Isothermal Compression

CORPORATION

United Technologies Research Center: Advanced Flow Battery

General Atomics and Affiliated Companies: Soluble Lead Flow Battery

ABB: 2G-HTS SMES

Boeing: High-Energy Flywheel

Transformative Electrochemical Flow Storage System

United Technologies Research Center

Clipper

Pratt & Whitney
A United Technologies Company

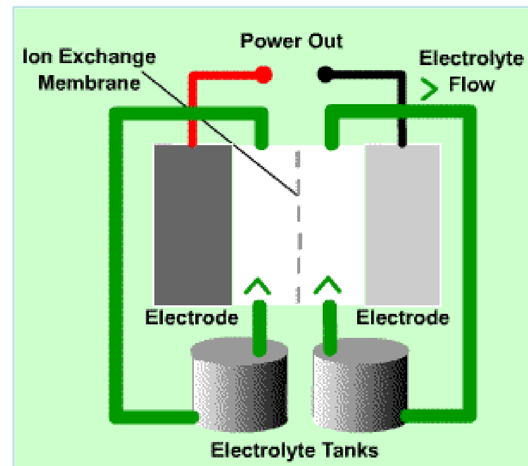
Pratt & Whitney Rocketdyne, Inc.

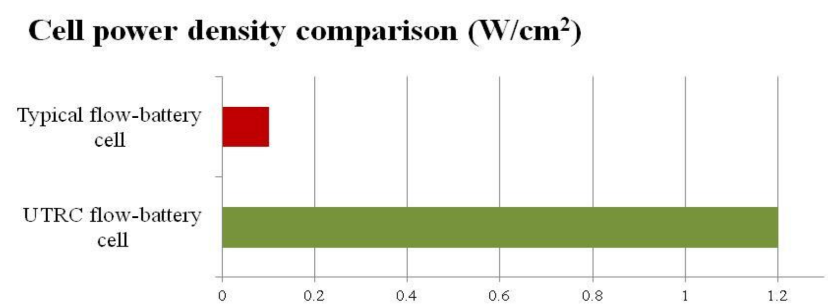
A unique flow battery cell that provides 10X increase in power density

Novel cell will reduce system cost by 2-4X

Initially Vanadium redox chemistry

Jump-starts domestic effort in redox flow batteries, which had migrated out of North America





Rechargeable Iron-Air Battery

<u>Cell Reaction:</u>

$$Fe + H_2O + ½\ O_2 \Leftrightarrow Fe(OH)_2$$

<u>Anode:</u> (discharge)

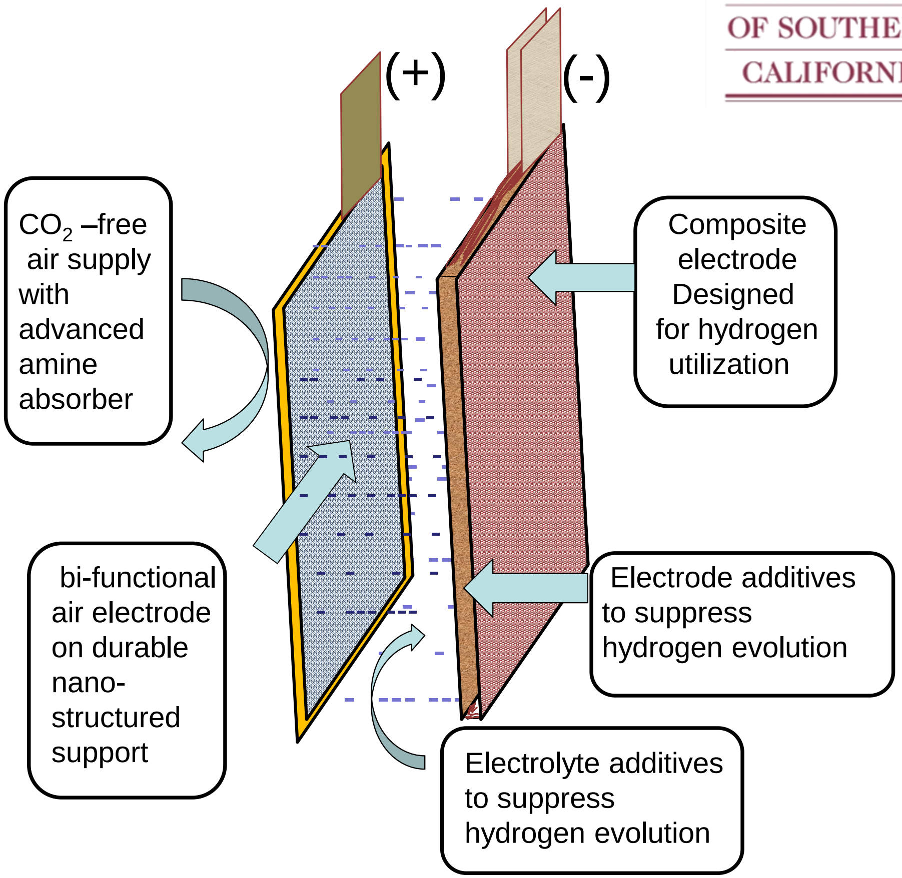
$$Fe + 2OH^- \Rightarrow Fe(OH)_2 + 2e^-$$

<u>Cathode:</u> (discharge)

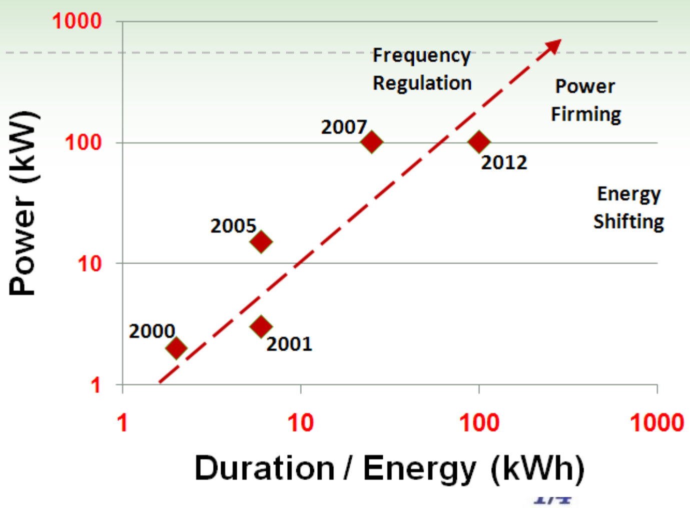
$$½\ O_2 + H_2O + 2e^- \Rightarrow 2OH^-$$

< $100/kWh & >5000 cycles
high power, low cost,
electrochemical storage

"Iron is Cheap, Air is Free"

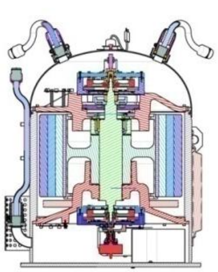


State of the Art Flywheel Storage Progression



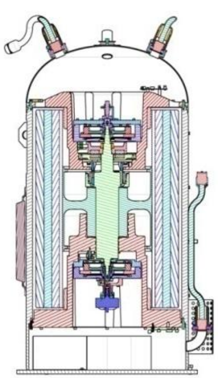
Beacon POWER

2 KWH 2002044



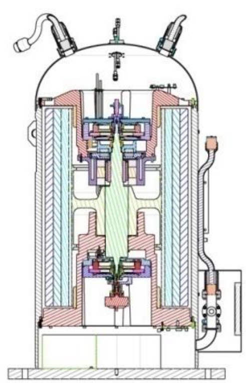
2000

6 KWH 2002046



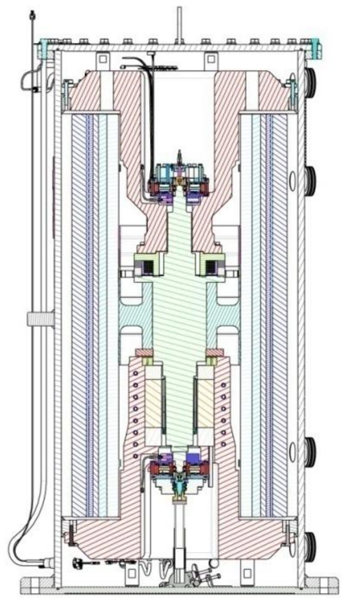
2001

DEMO 2002053



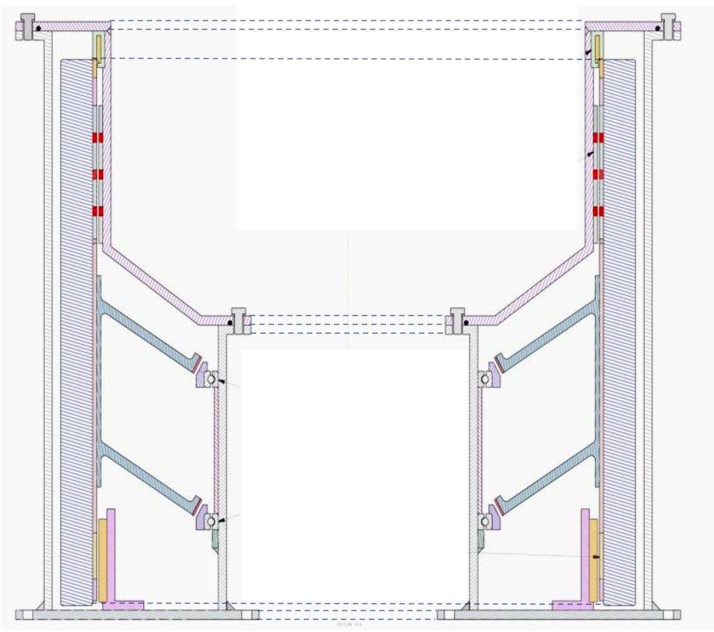
2005

25 KWH 2002060



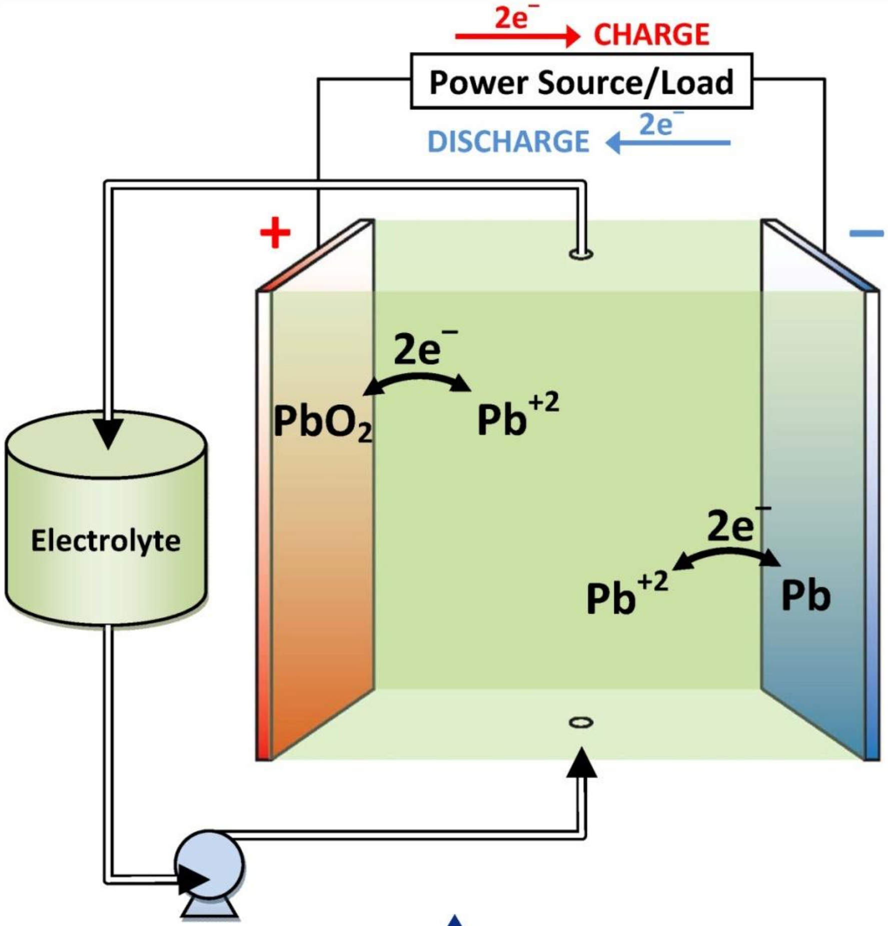
2007

100 KWH ARPA-E Supported



2012

Grid Scalable Lead Acid Battery



Innovations

- MSA-based electrolyte
- Carbon-based electrodes
- Flow-battery design

Impact

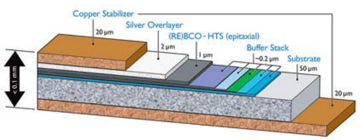
- Cost Reduction
- Grid Scalable
- Cycle-life Improvement

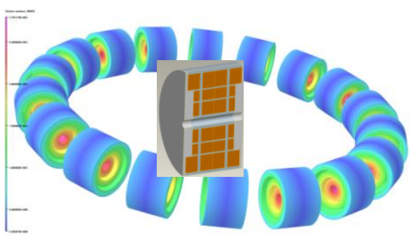
GENERAL ATOMICS

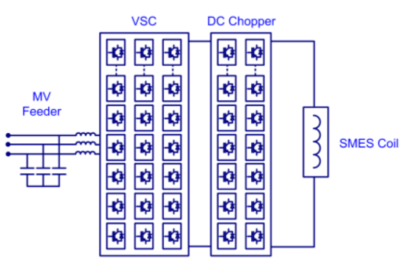
UCSD Jacobs | Department of NanoEngineering

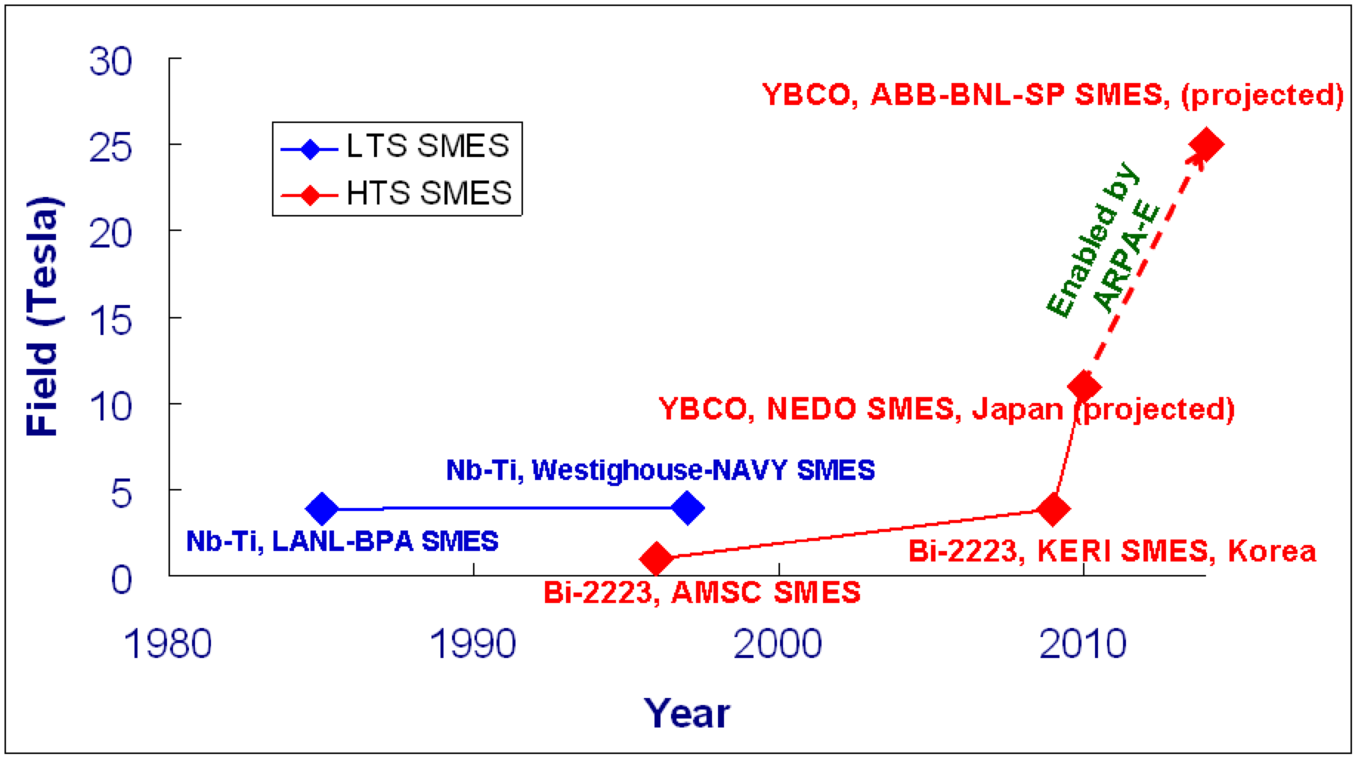
Superconducting Magnet Energy Storage

ABB BROOKHAVEN NATIONAL LABORATORY SuperPower Inc. UNIVERSITY of HOUSTON

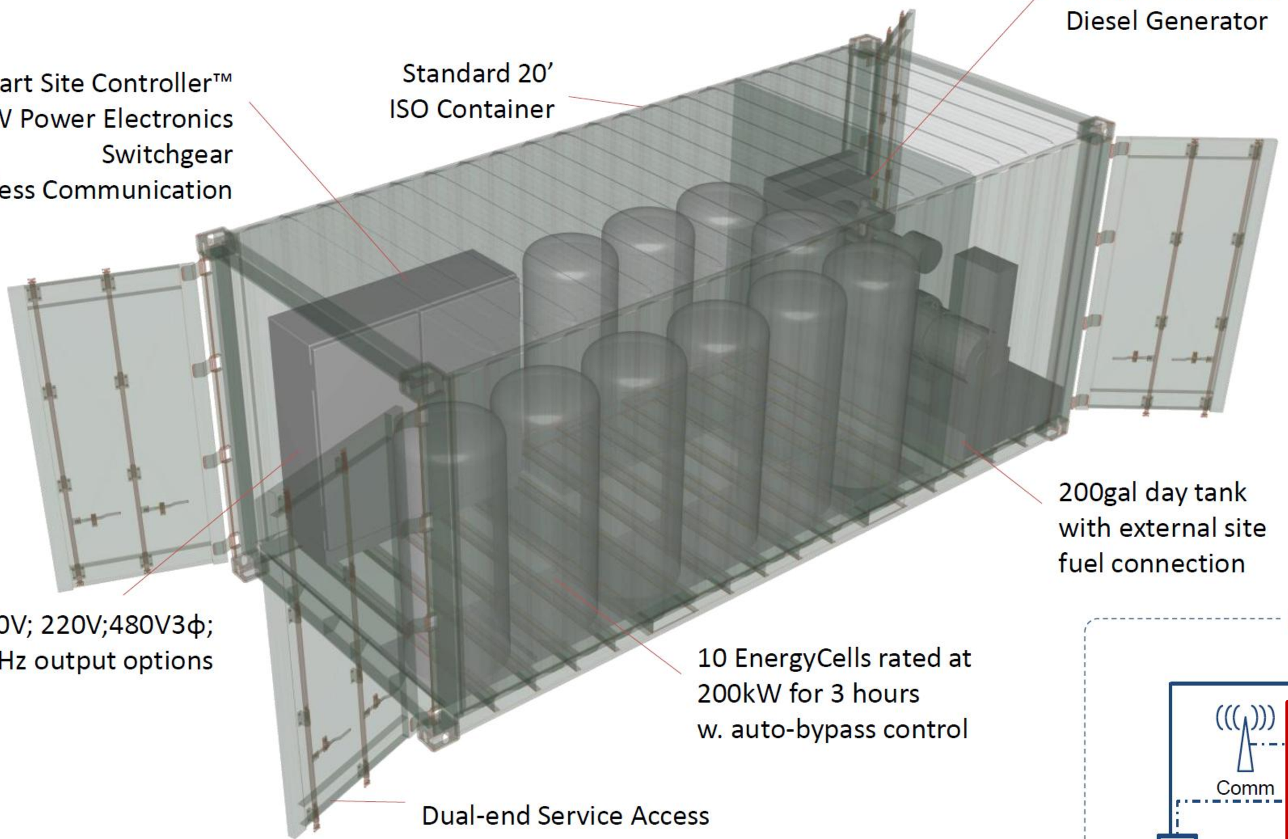








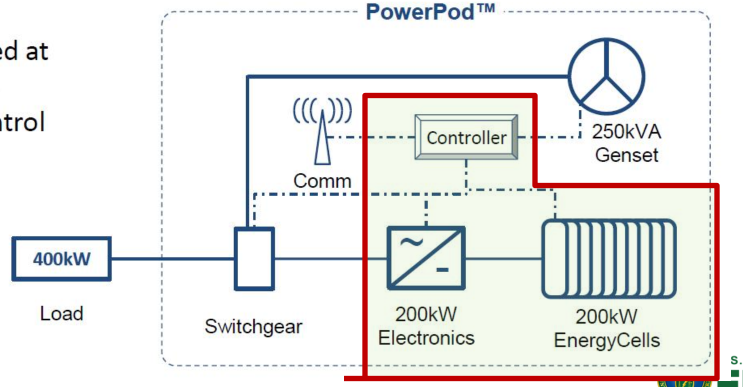
400kW PowerPod™ System Concept



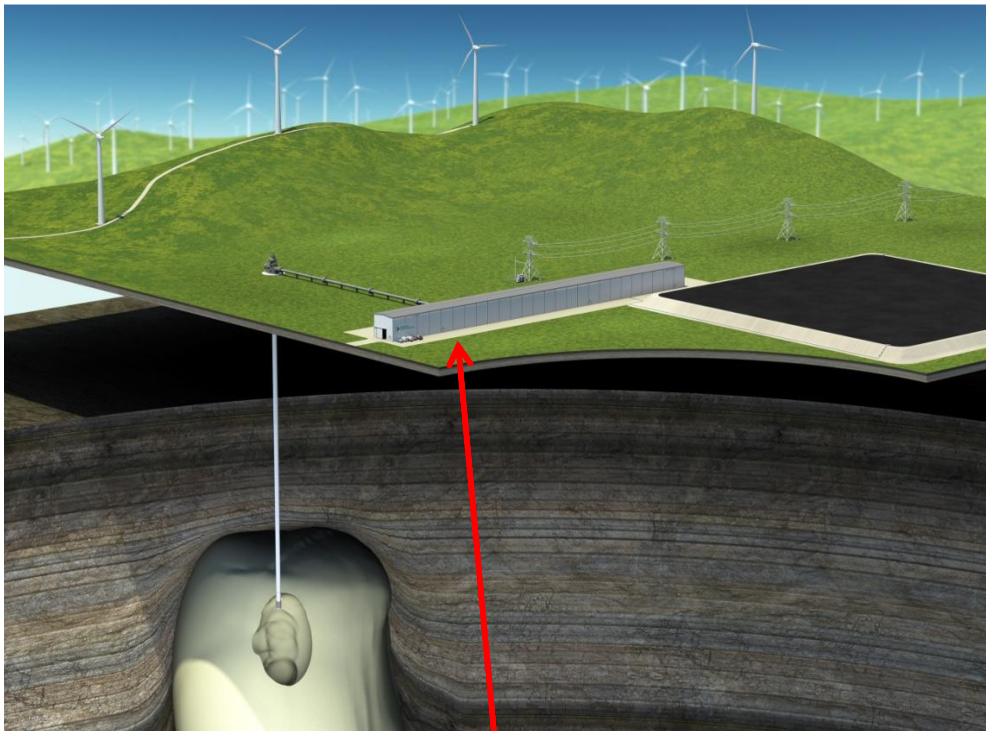
Standard 28”ϕ steel ASME, NFPA58 conforming tank

<u>ARPA-E Project</u>
Power Cell for
>20 Year Lifetime

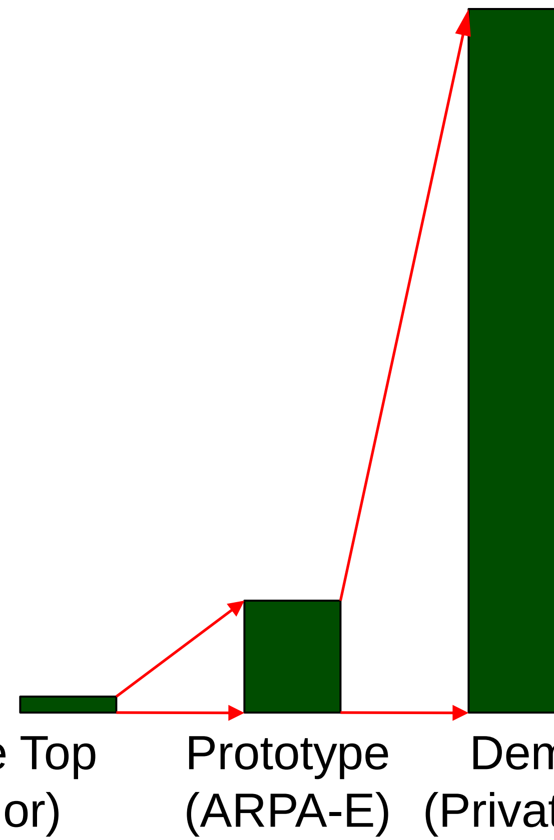
Unlike Today’s
Technology
~2 Years



Fuel-Free Isothermal Compressed Air Storage



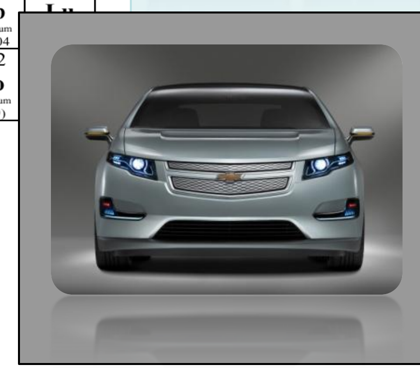
Innovative Technology:
New Isothermal Compressor / Expander



Critical Materials in Clean Energy

1 H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71
90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	



Vehicles

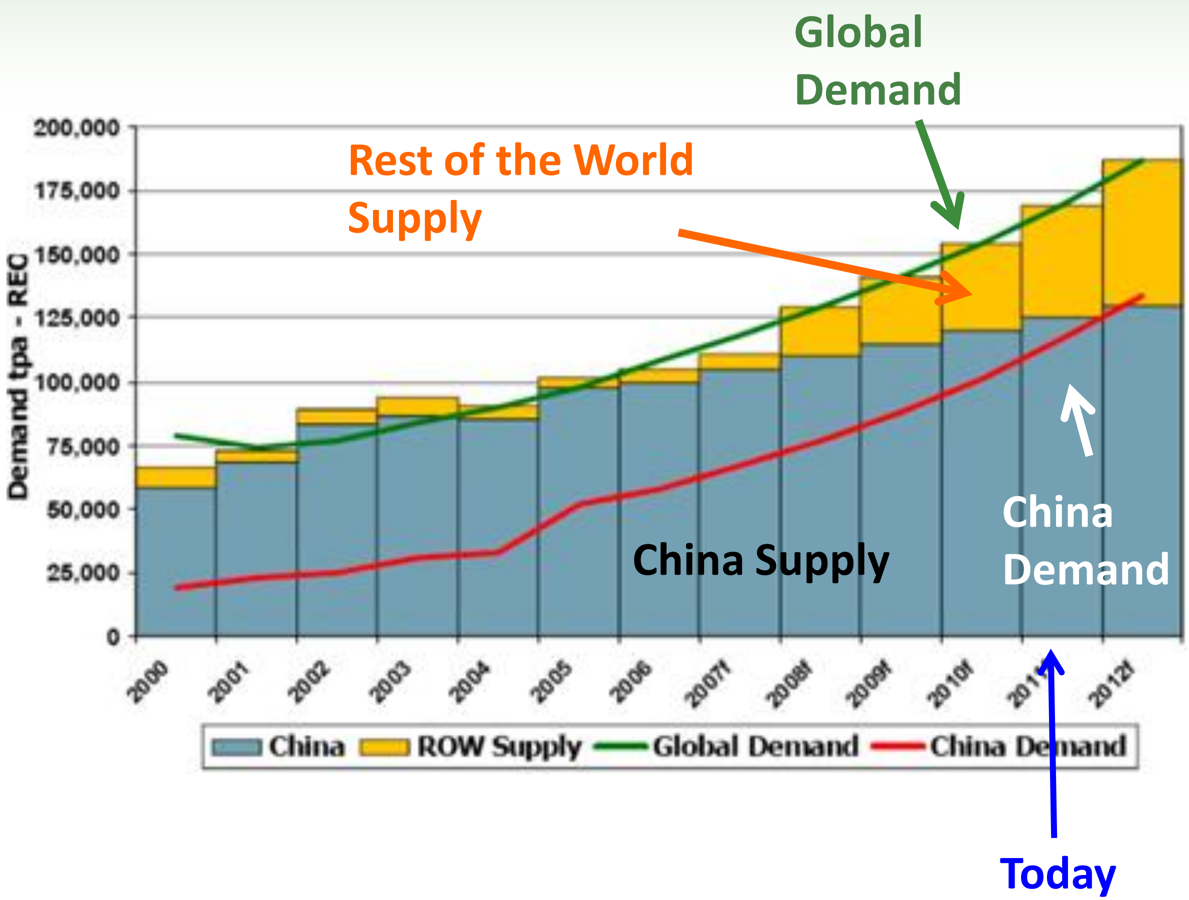
Lighting

Solar PV

Wind

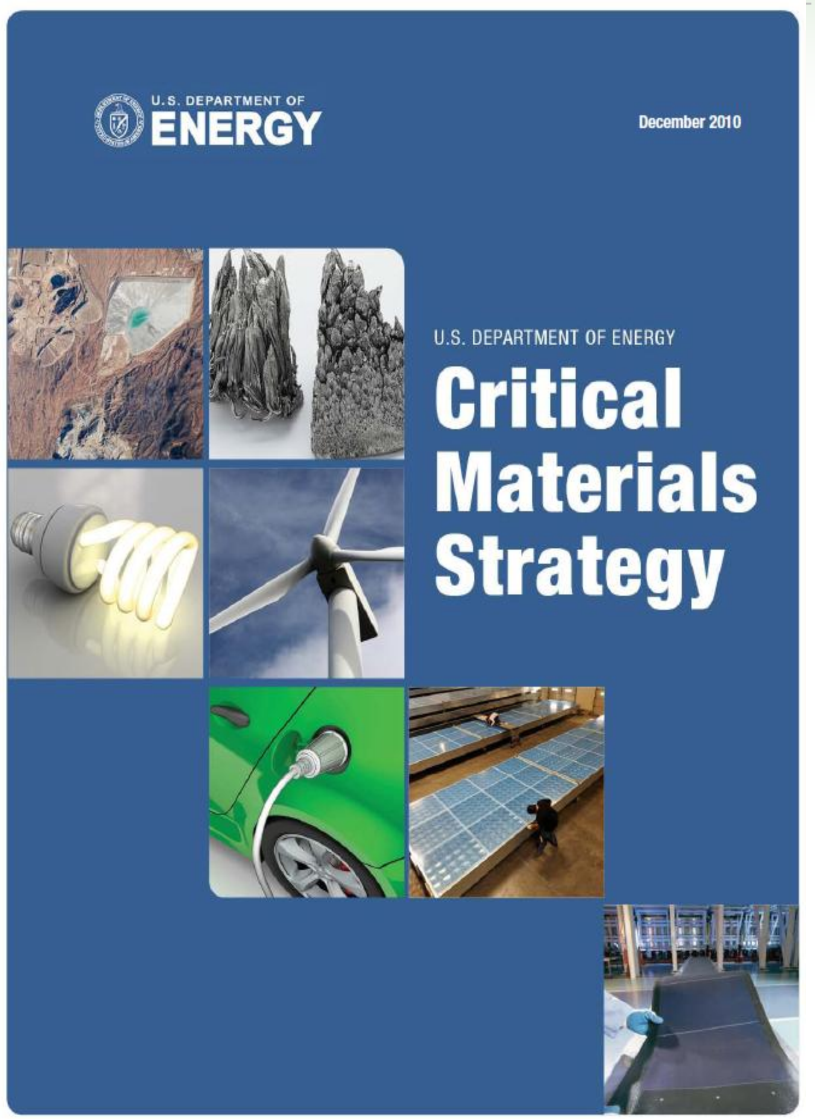
US DOE: Critical Materials Strategy (Dec 2010)

Shifting Economics Of Rare Earth Materials

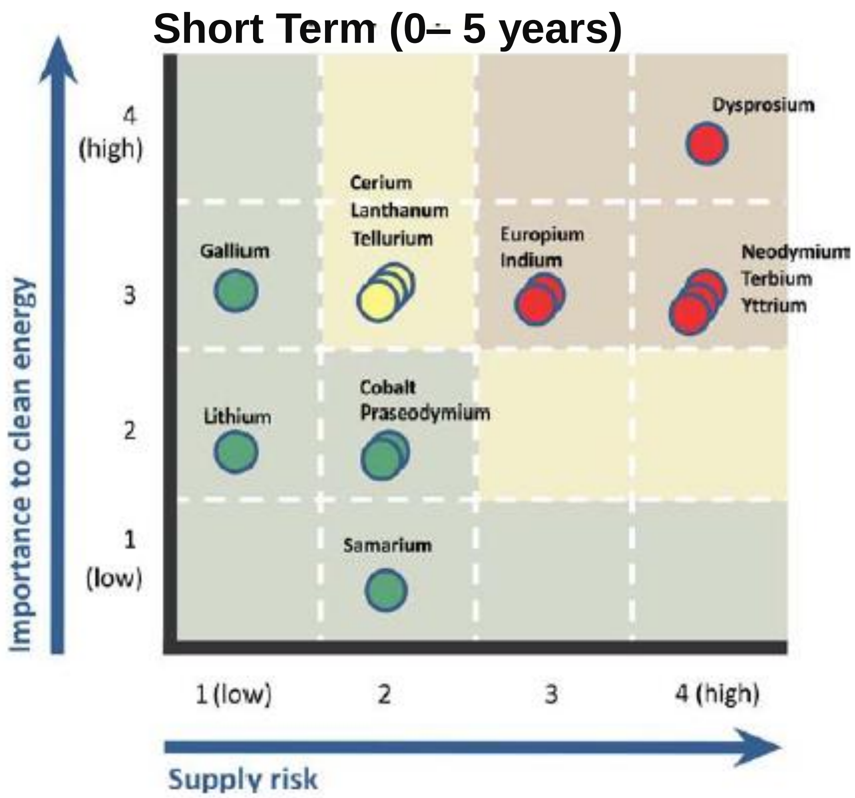


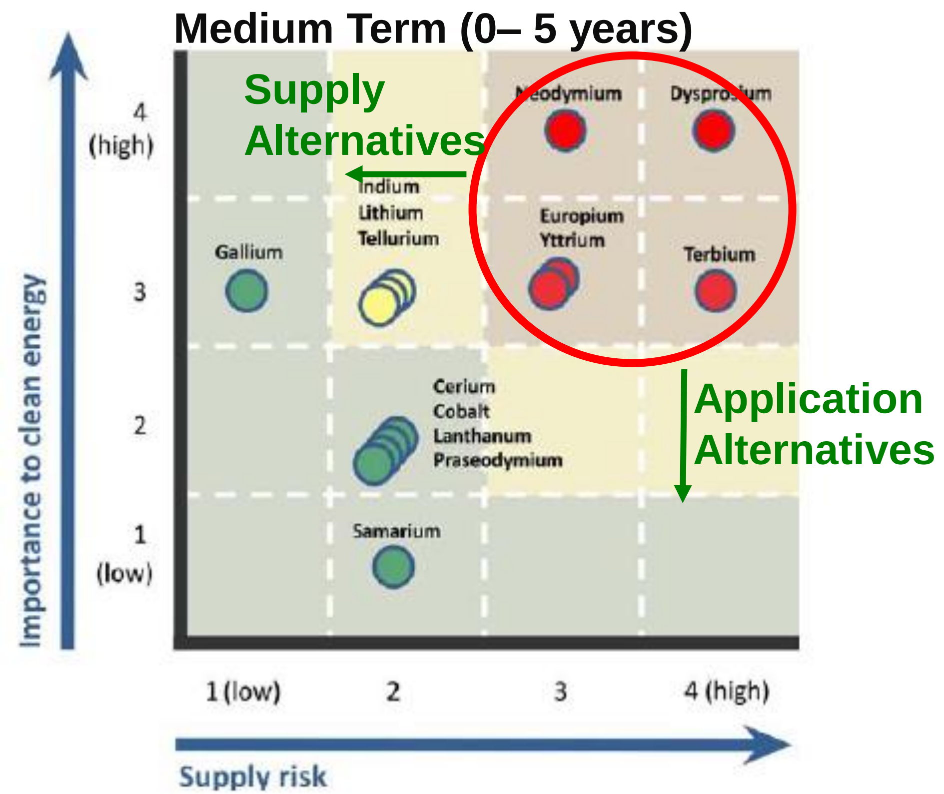
Within 5 Years: World's Dominant Supplier of Rare Earth Materials May Switch From a Net Exporter to a Net Importer

Coordinated Critical Materials Effort



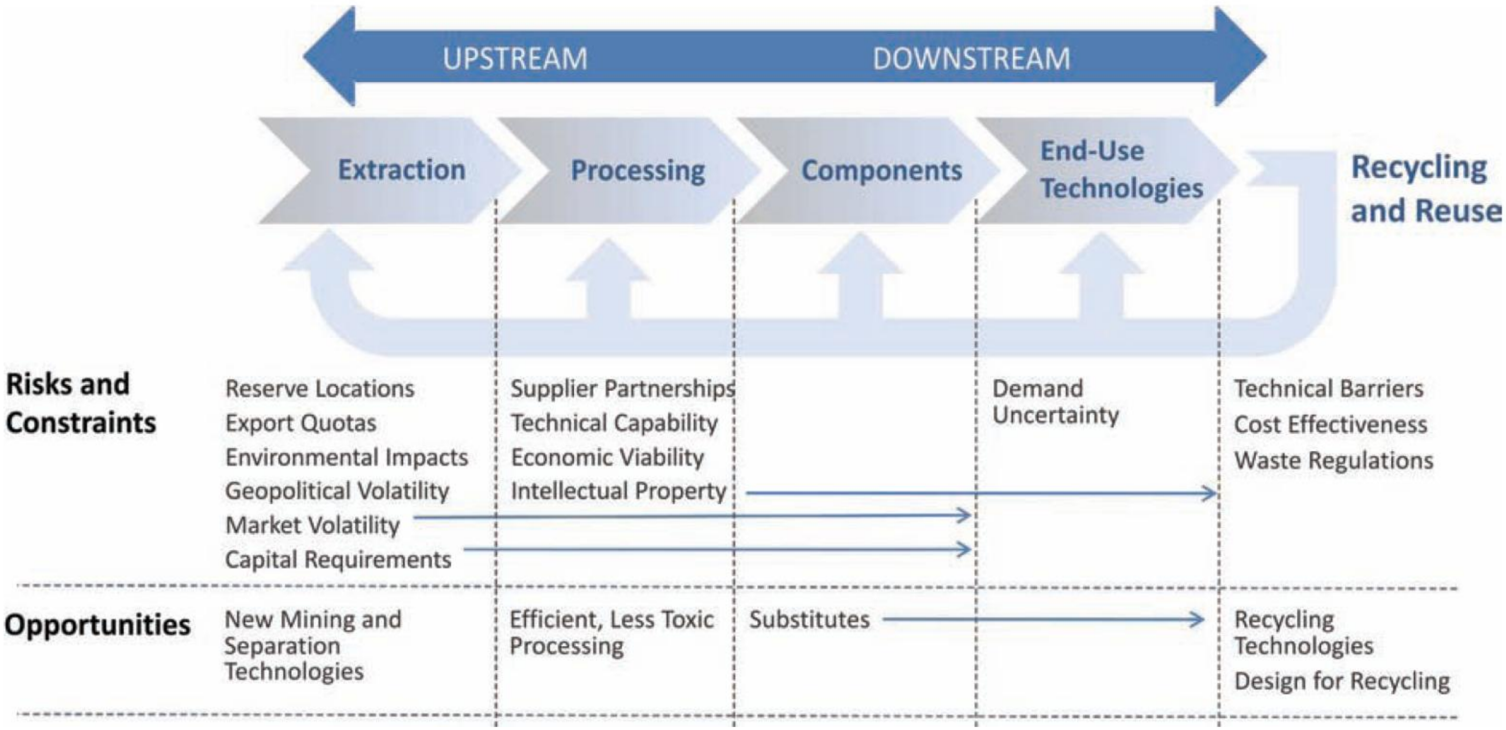
Rare Earth Criticality by Element



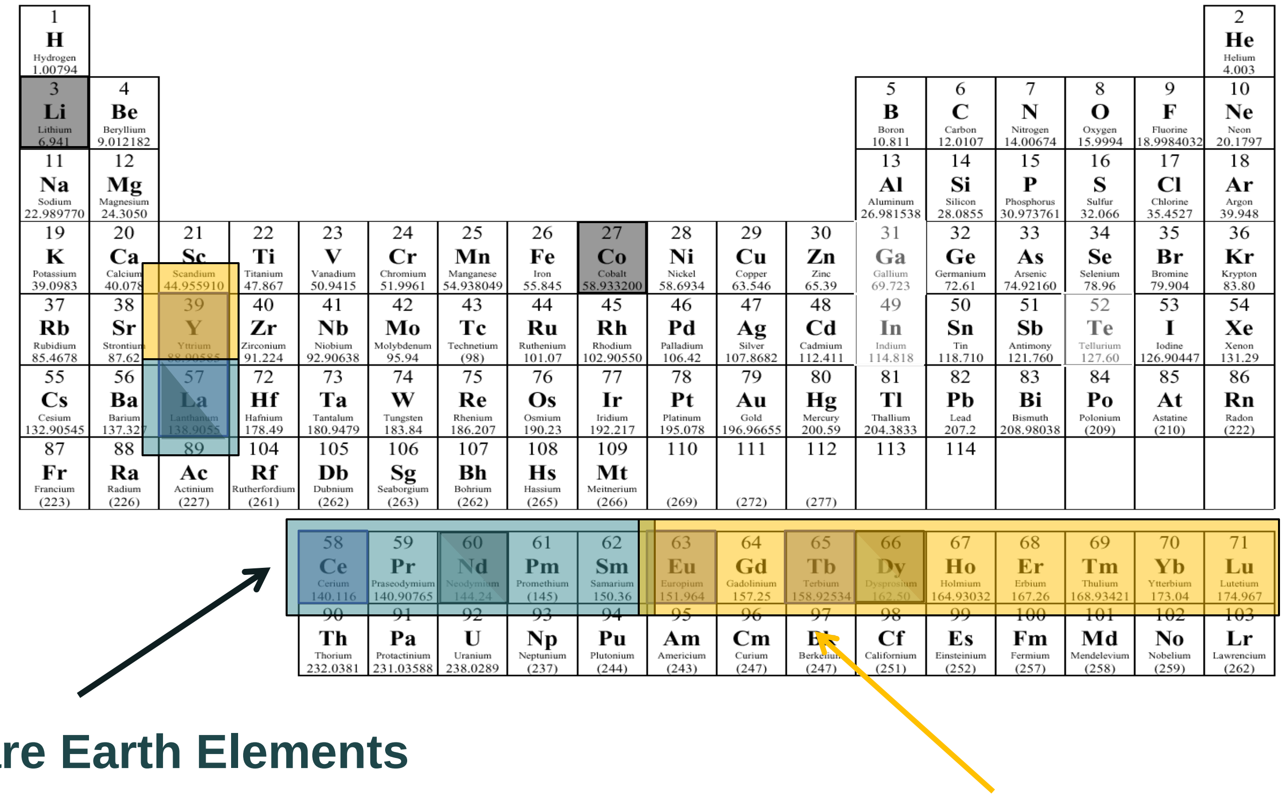


US DOE: Critical Materials Strategy (Dec 2010)

Developing Technology Alternatives Across Supply Chain



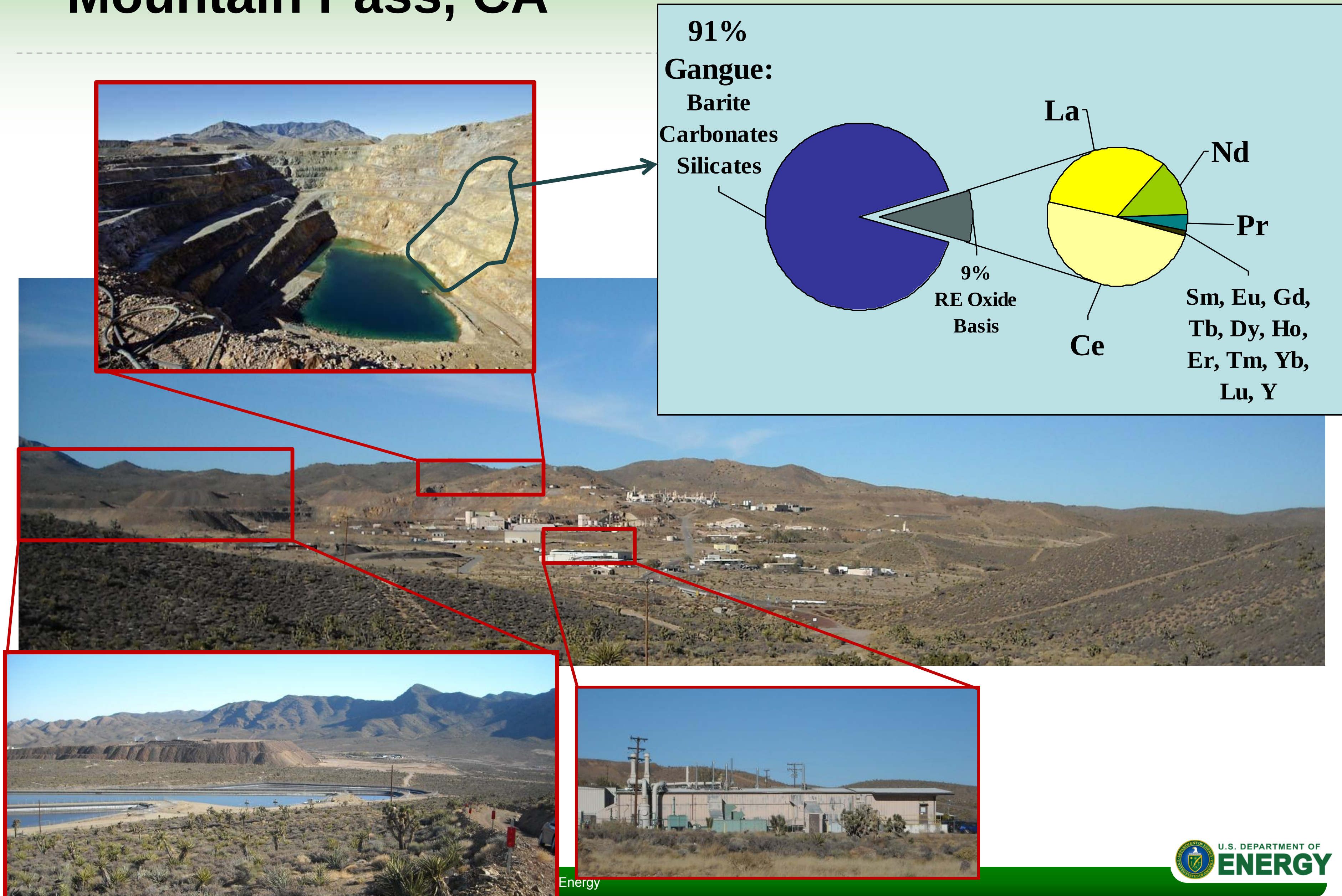
Possible Approach: Get Most From Available Supply



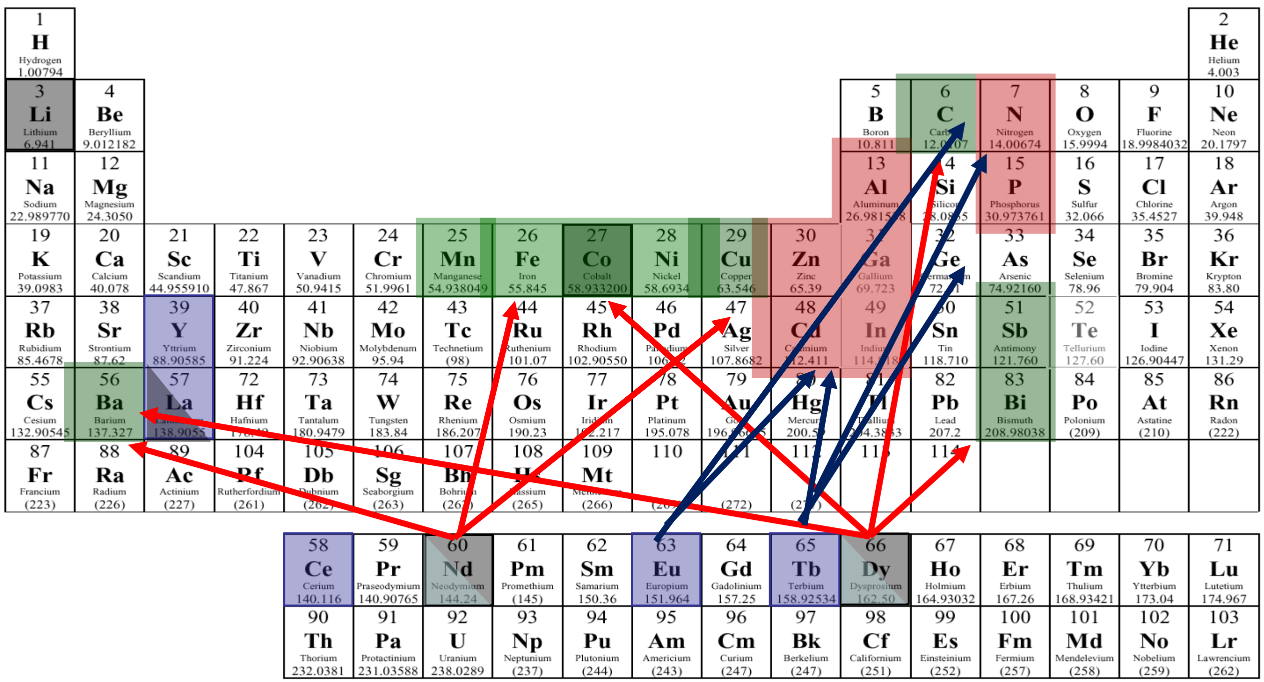
Light Rare Earth Elements

Heavy Rare Earth Elements

Molycorp Rare Earth Facility
Mountain Pass, CA



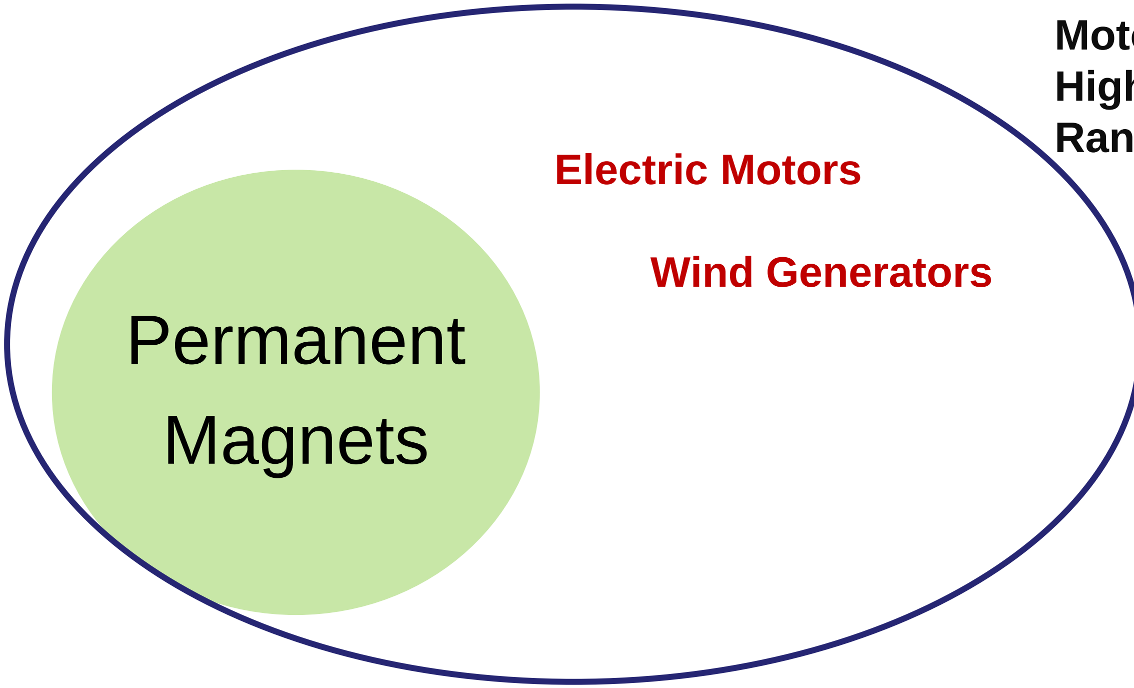
Possible Approach: Eliminate Need for Material



REACT PROGRAM: WORKSHOP GUIDED FOCUS

REACT Domain Space

Alternatives to RE Permanent Magnet Electric Motors for High Efficiency across Range of Torque / Velocity

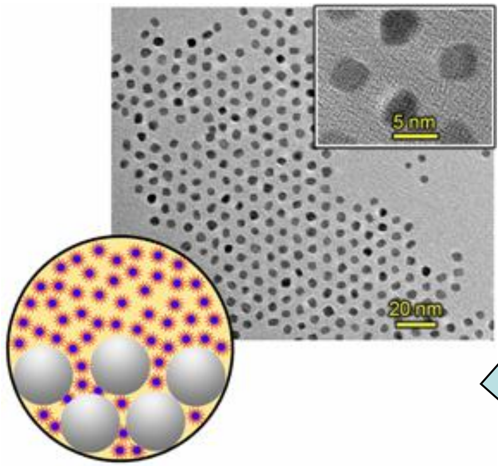


RE Permanent Magnet Content in Direct Drive Generators as Power Goes to ~10MW

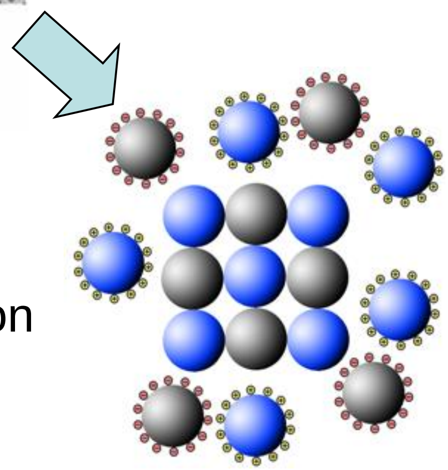
Application Technologies

High Energy Permanent Magnets for Hybrid Vehicles and Alternative Energy (FOA1)

G. Hadjipanayis – U Del (Subs V. Harris - Northeastern, D. Sellmyer - U of Nebraska, R. McCallum - Ames, E. Carpenter - VCU, J. Liu – EEC **Fed: $4462K – Match $1146K, 36 months**



Synthesis

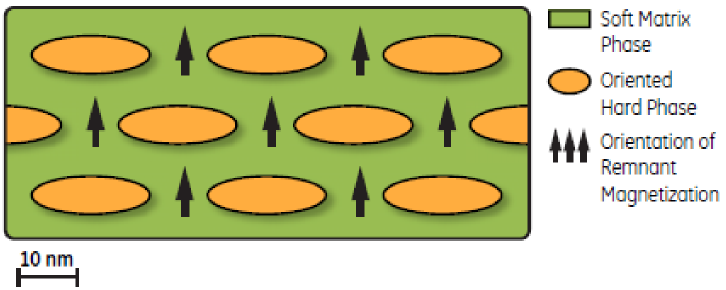


Consolidation

- Target: $(BH)_{max}$> 100 MGOe, no rare earth restriction (RT)
- Permanent magnets based on newly-discovered compounds
- New doped Fe-Co intermetallics
- Anisotropic nanocomposite magnets via a bottom-up fabrication routes
- Modeling for validation

Transformational NanoStructured Permanent Magnets

F. Johnson et al. (GE Global Research) Fed: $2250K – Match $750K, 24 months



NdFeB: (Hard)

H_c = 10,000 - 12,000 Oe

B_r = 11-15 kG

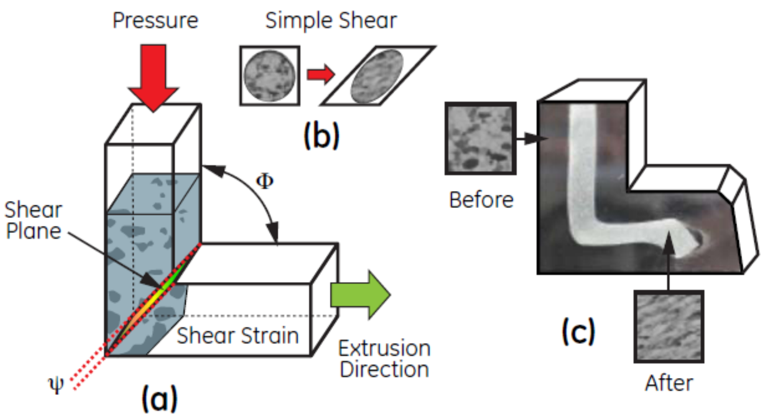
Fe: (Soft)

H_c = 0.05 Oe

B_r = ~22 kG

Core@Shell Hard/Soft Exchange Spring Coupled Nanocomposite Magnets with:

- 80 MGOe (vs 59 MGOe NdFeB)
- 59 MGOe with 80% less rare earth



Questions?