ADVANCED RESEARCH PROJECTS AGENCY (ARPA-E)

MARK JOHNSON
PROGRAM DIRECTOR

Workshop on Rare Earths
Arlington, VA

December 2010

www.arpa-e.energy.gov

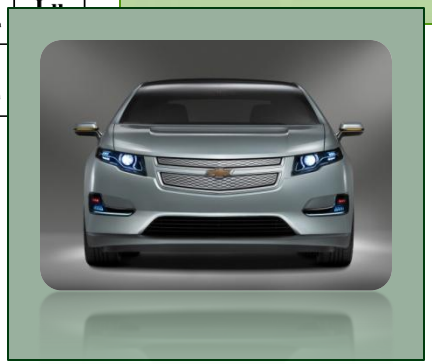
Gentlemen, we have run out of money. It is time to start thinking.

Sir Ernest Rutherford

Key elements in clean energy supply chain
From DOE Wide Analysis

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 Lu
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

Key elements in clean energy supply chain
From DOE Wide Analysis by DOE/PI

Traditional Energy

Smart Grid

Vehicles

Lighting

Solar PV

Wind

Technology Opportunity Areas for Study

- Vehicles
- Lighting
- Solar PV
- Wind
- Traditional Energy
- Smart Grid

- Batteries
- Phosphors
- Transparent Contacts
- Permanent Magnets
- Oxygen Separators
- Catalysts

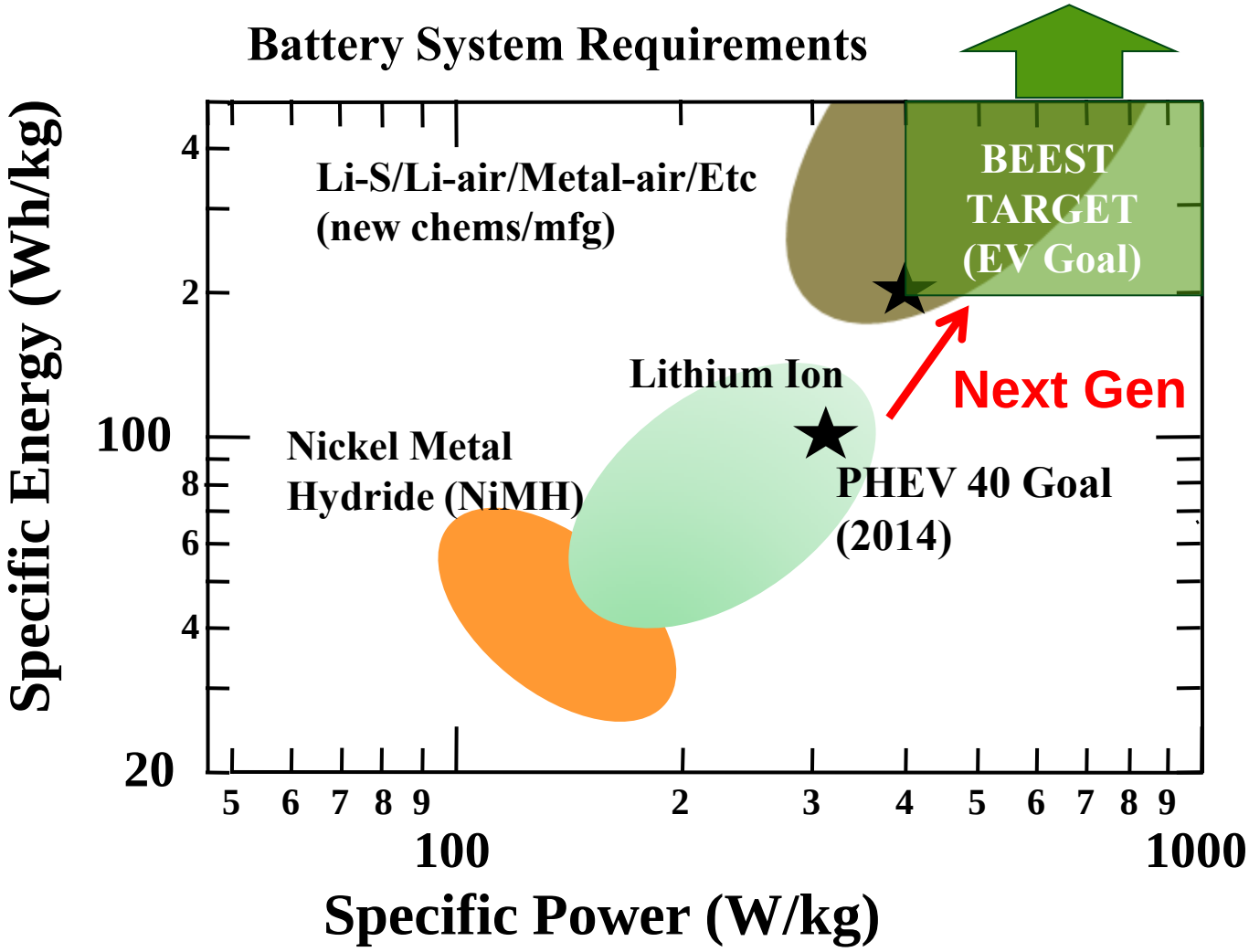
Opportunities For New, Disruptive Approaches to Technology Needs

Develop Metrics which Drive New Learning Curves and Approaches

We have a rare earth materials challenge.

THIS WORKSHOP IS ABOUT IDENTIFYING POSSIBLE SOLUTIONS

Batteries for Electrical Energy Storage in Transportation (BEEST) Program Targets



Storage Cost

Current Target: $1,000/kWh

BEEST Target: $250/kWh

Source: David Howell, DOE Office of Vehicle Technologies, 2009.
International Energy Agency, *Technology Roadmaps: Electric and Plug-in Hybrid Electric Vehicles*

BEEST Portfolio

10 Advanced Prototyping Projects: $47.1M
4 Seedlings: $5.7M
TOTAL: $52.8M/3 years

System Targets:
200-400 Wh/kg
300-800 Wh/L

Upside

Ultra-High Energy

Recapping Inc.

STANFORD ENGINEERING

FastCAP SYSTEMS™

(Capacitive)

POLYPLUS

(Li-Air)

SION POWER

(Li-S)

24M

(Flow Batt)

FLUIDIC ENERGY

(Metal-Air)

MISSOURI S&T

(Li-Air)

REVOLT TECHNOLOGY

(Zn-Air)

Pellion Technologies Inc.

(Mg-Ion)

Advanced Lithium

PLANAR ENERGY

(Solid State Li)

envia SYSTEMS

(Si anode)

APPLIED MATERIALS

(Li Ion Mfg)

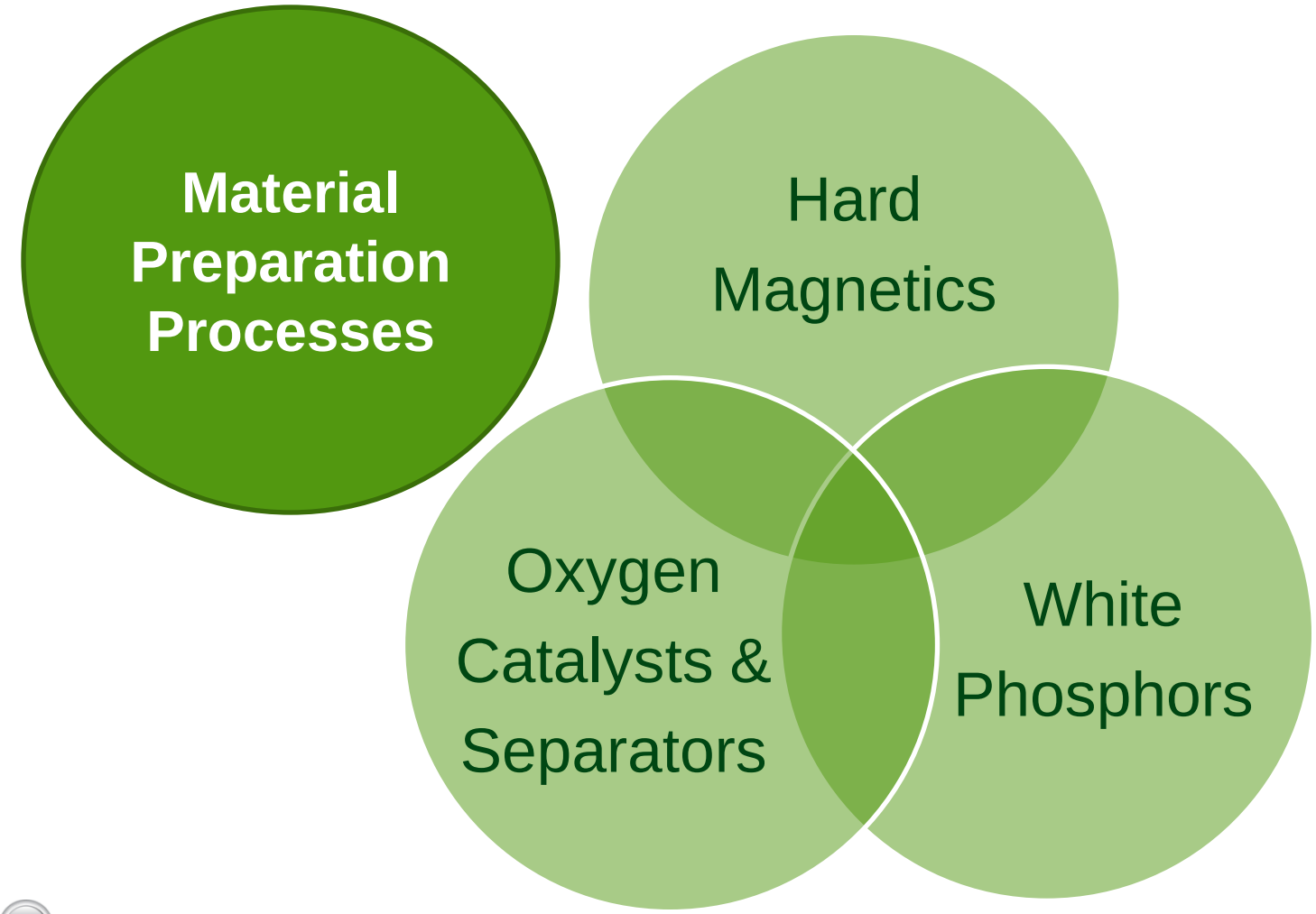
Inorganic Specialists, Inc.

(Si anode)

Infrastructure Compatible High Energy Materials

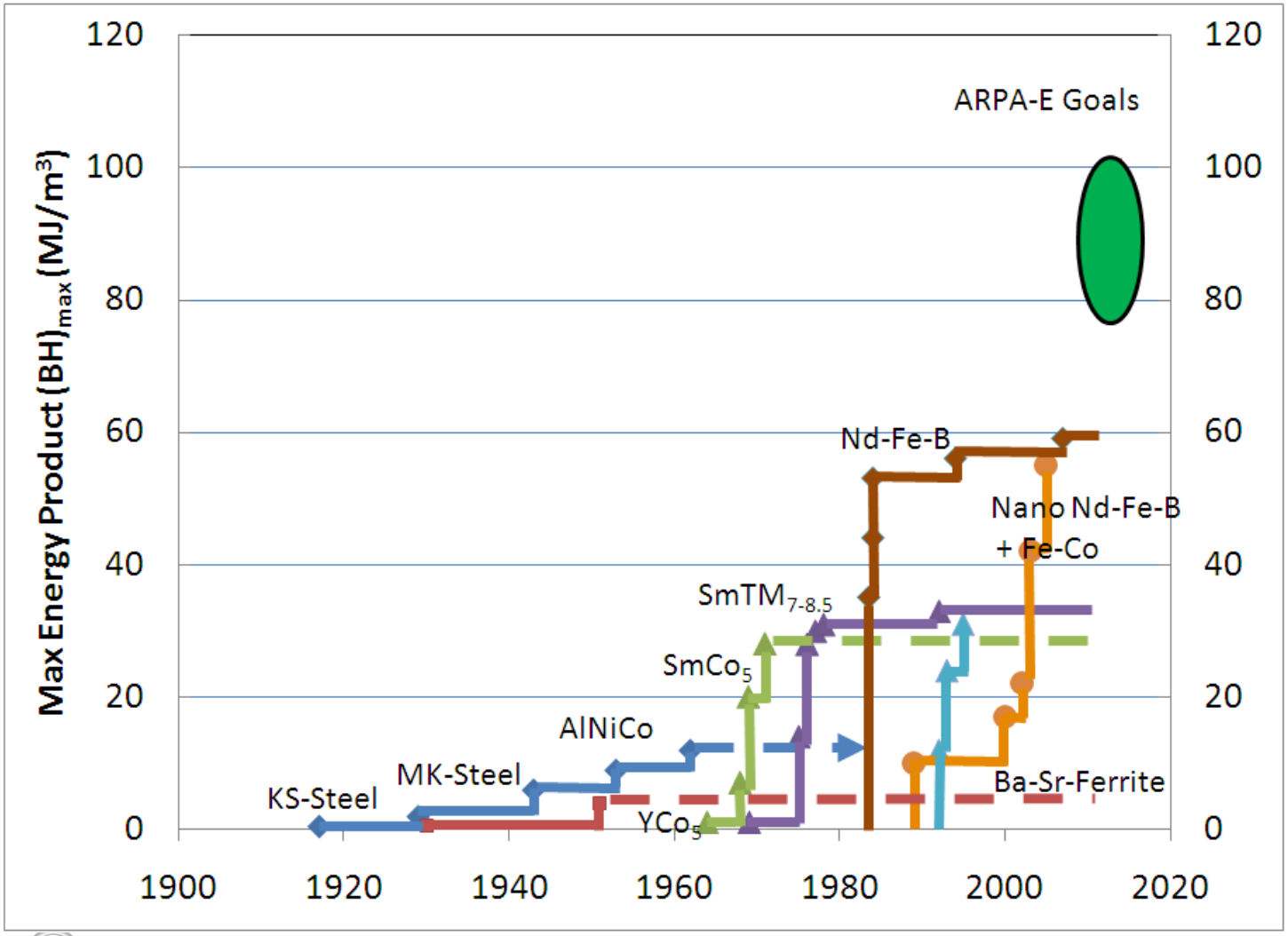
"Time to Market"

Technology Domains

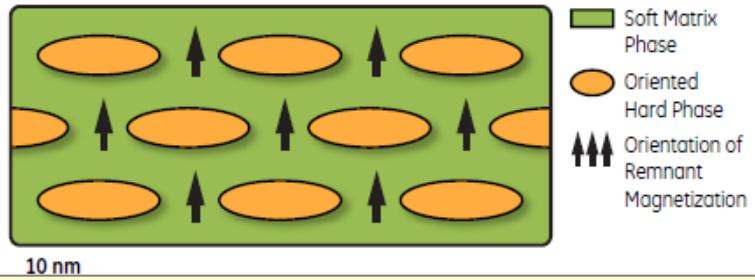


Supply Technologies → **Demand Technologies**

ARPA-E *New magnet structure and chemistry have disruptive potential*



Current program – ARPA-E
Transformational nanostructured permanent magnets (PM)



Hard Phase

H_c = 10,000 - 12,000 Oe

M_r = 11-15 kG

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

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

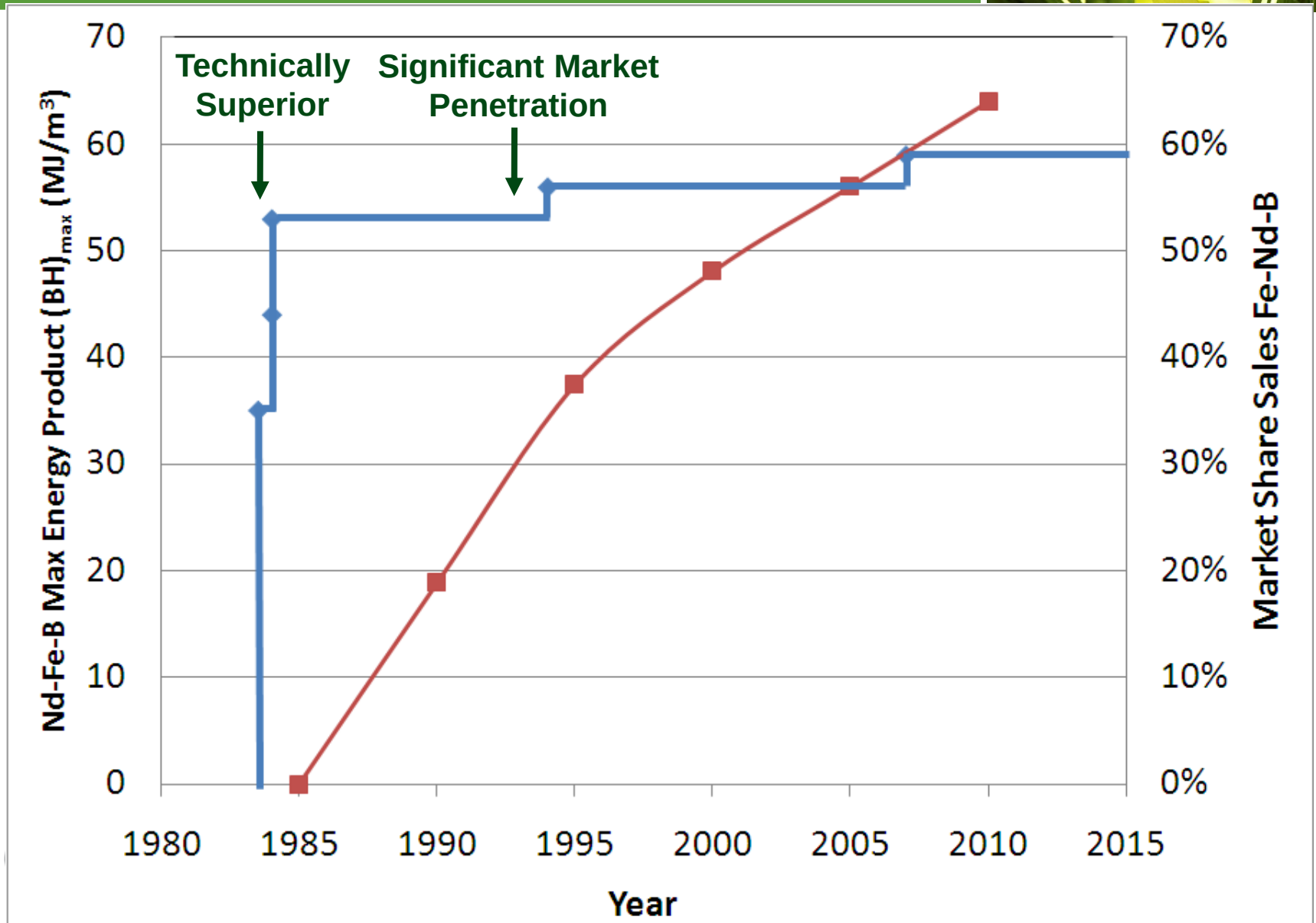
Soft Phase:

H_c = ~0.05 Oe

M_r = ~22 kG

Nanocomposite exchange spring coupled permanent magnets with high energy product and less rare earths

SIGNIFICANT MARKET PENETRATION WITHIN TEN YEARS WITH Nd-Fe-B DISRUPTIVE TECHNOLOGY



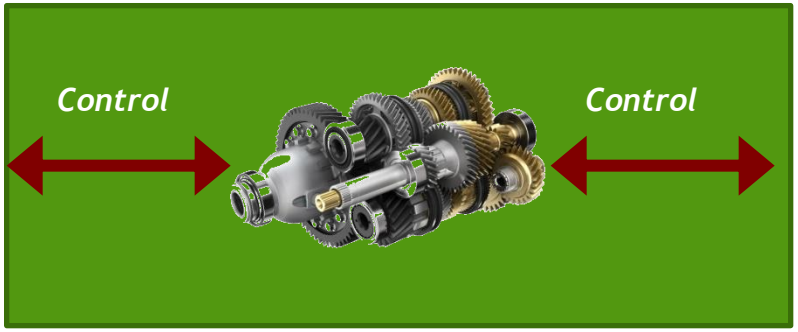
WHAT IS POWER ELECTRONICS?

Power electronics is the electrical version of a gear box/transmission

Power Source

Load

Power Source



Load

Imagine driving a car always in 4th gear…

…imagine what this would do to fuel efficiency and drivability

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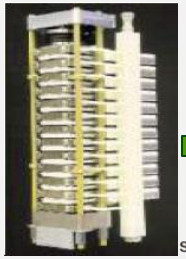
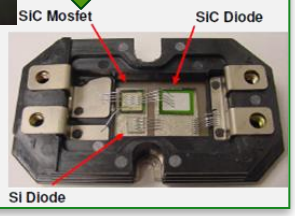
Power electronics need improvement in applications across the entire energy sector (ADEPT)

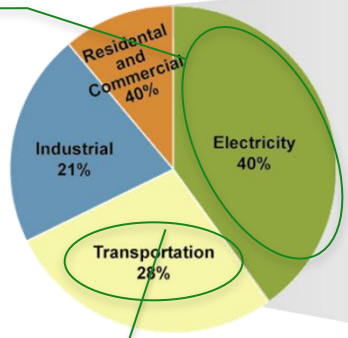
Distribution & Transmission



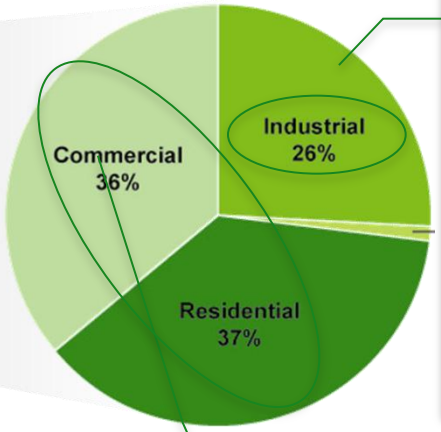
>13 kV, 50kHz SiC transistors



Primary Energy Use by Sector, 2008



Share of Electricity Consumed by Major Sectors of the Economy, 2008



Industrial

Inverter drives motor

Automotive

Lighting

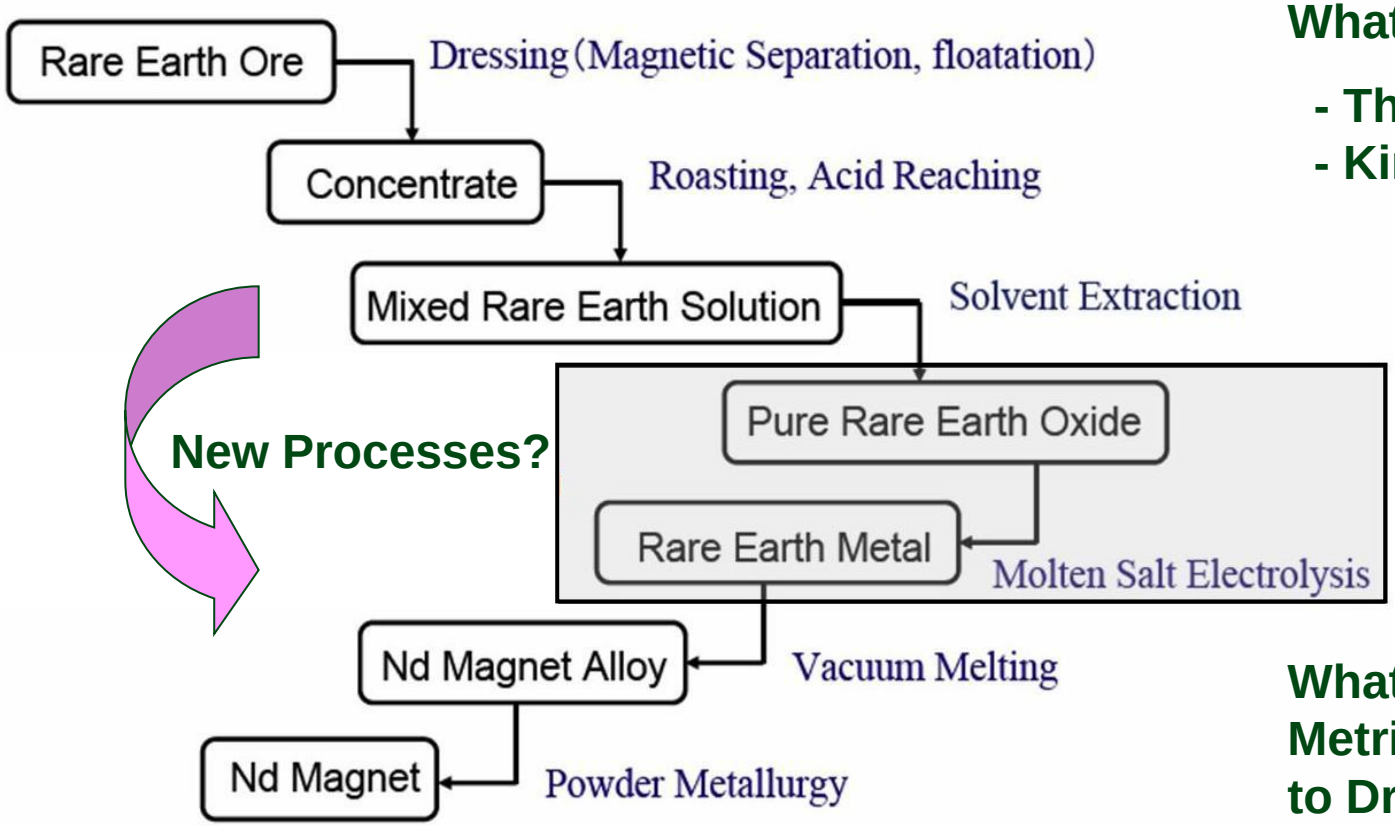
Existing 25 W AC-DC SSL Driver

130 mm x 45 mm x 25 mm

300X reduction in power stage volume

Supply: Processing

Process from Rare Earth Ore to Nd Magnet



New Processes?

What are Ultimate Limits?

- **Thermodynamics**
- **Kinetics**

What are Economic Metrics and Goals to Drive Innovation?

Source: Takehisa Minowa Takehi, "Rare Earth Resources for Nd Magnetics: Their Present and Future," Magnetics Conference 2009

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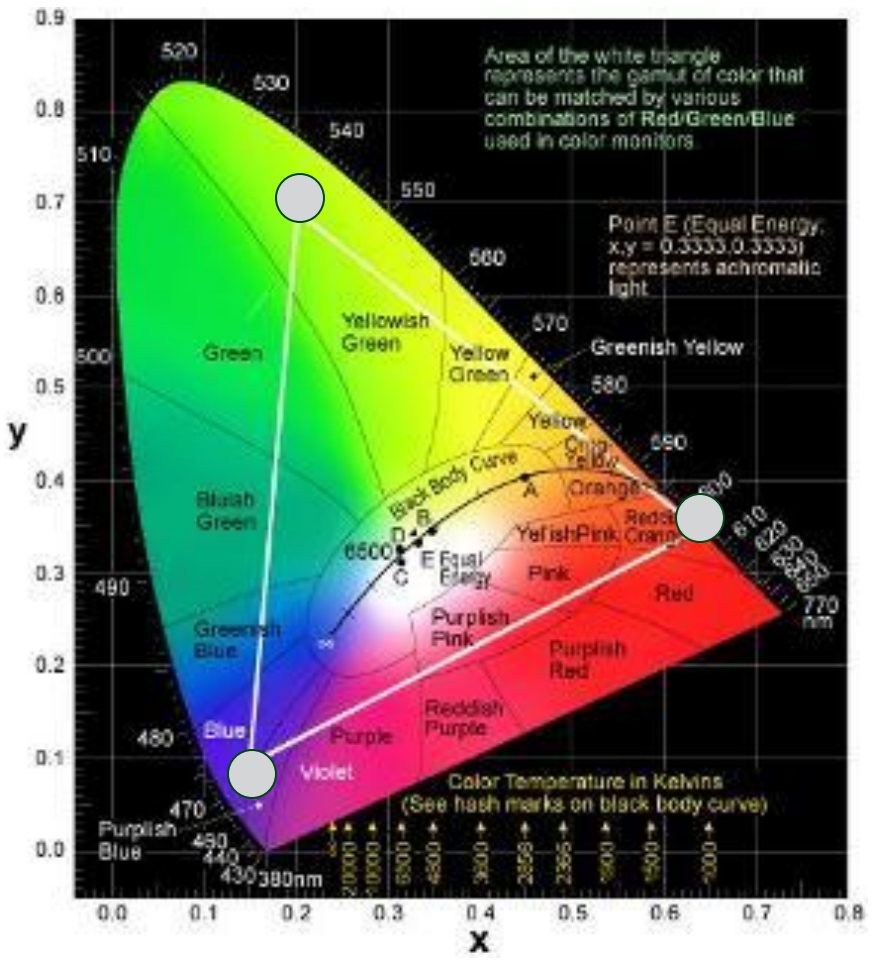
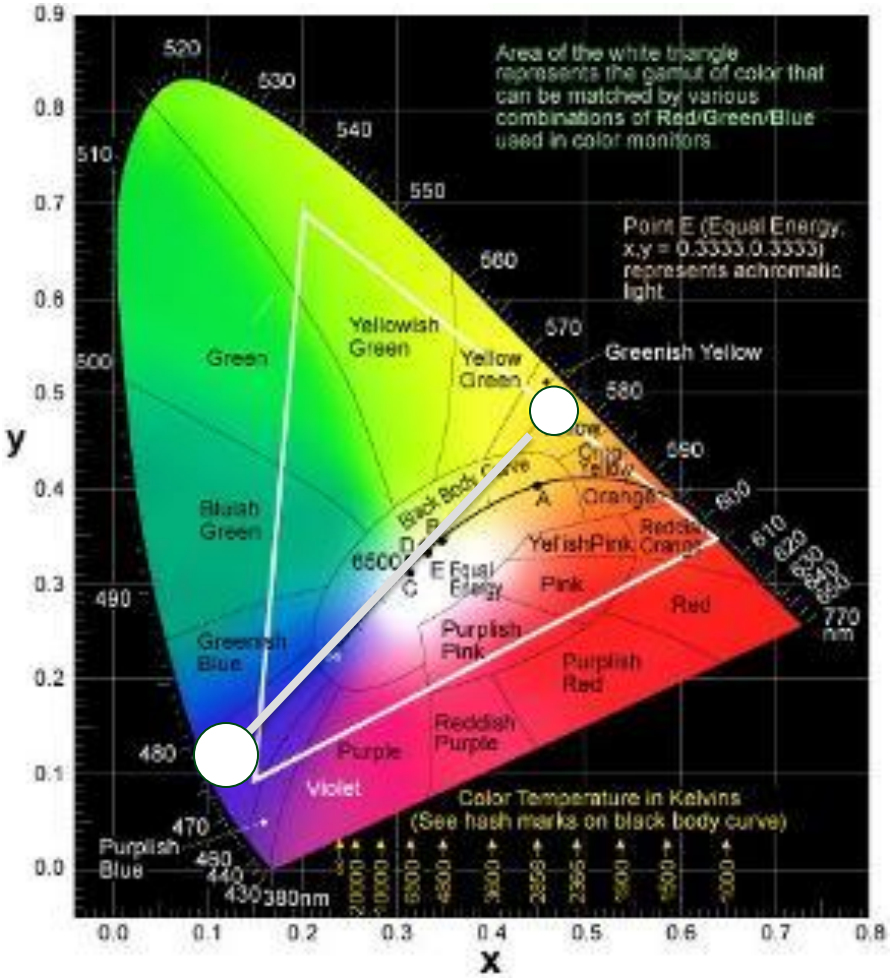
Application: Phosphors





DEMAND SIDE: CATALYSTS

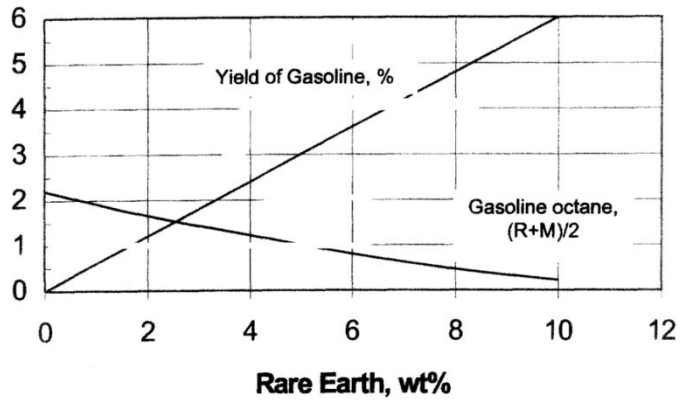
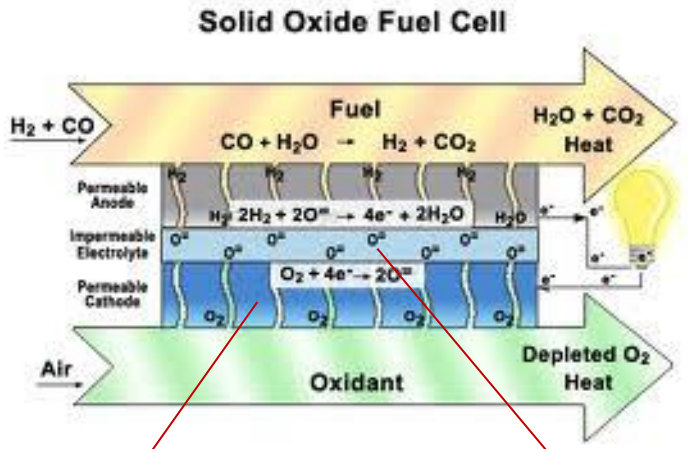


Figure 3-6. Effects of rare earth on gasoline octane and yield.



LSM Cathode **YSZ Separator**

ARPA-E BACKGROUND DEVELOPMENT

- Supply Side:
  - **Direct, Low Cost, Low Environmental Impact Processing Innovation**
- Demand Side Magnetics
  - **Hard Magnetics (Beyond U-Del and GE Projects)**
  - **New Motors + Power Electronics**
- Phosphors
  - **New chemistry, Shape and Size Effects**
  - **Low Defect (low non-radiative recombination) emitters**
- Catalysis and Separators
  - **SOFC Oxygen Permeable Ceramics and Cathodes**
  - **FCC and Post Combustion Catalysts**

Two Big Outcomes Desired

- Identification of Technical Opportunity Which Would Potentially Have Significant Impact on Rare Earth Challenge

- Determination of Potential Relevant Metrics Which Would Drive Innovation

Plan for the Day

Time	Activity	
8:00 AM	Registration / Coffee / Breakfast	
8:15 AM		
8:30 AM	Kick-Off Arun Majumdar (ARPA-E)	
8:45 AM	Overview of Day Mark Johnson (ARPA-E)	
9:00 AM	US-Japan Rapporteur Diana Bauer (DOE HQ/PI)	
9:15 AM	US-EU Rapporteur Bill McCallum (Ames)	
9:30 AM	Current State of the Art for Supply Brock O'Kelly (Molycorp)	
9:45 AM	Current State of the Art for Applications Talk #1 Steve Duclos (GE)	
10:00 AM	Current State of the Art for Applications Talk #2 Frederick Pinkerton (GM)	
10:15 AM	Break	
10:30 AM	SUPPLY 1 Karl Gschneidner (Ames)	MAGNETS 1 Steve Constantinides (Arnold Magnet)
10:45 AM	SUPPLY 2 Eric Peterson (INL)	MAGNETS 2 George Hadjipanayis (Univ. of Delaware)
11:00 AM	SUPPLY Short presentations, dialog and discussion Gallery 1 Facilitator: Eric Toone Rapporteur: Jim Miller ARPA-E Notes: Brenda, Karma	MAGNETS Short presentations, dialog and discussion Gallery 3 Facilitator: Danielson, Aron Rapporteur: Steven Boyd ARPA-E Notes: Nick, Rusty
11:15 AM		
11:30 AM		
11:45 AM		
12:00 PM		
12:15 PM	Break for Lunch	
12:30 PM	Keynote Cyrus Wadia (OSTP)	
12:45 PM		

1:00 PM	Break	
1:15 PM	CATALYSTS 1 Jim Katzer (Rive Technology)	PHOSPHORS 1 Jennifer Hollingsworth (Los Alamos)
1:30 PM	CATALYSTS 2 Scott Barnett (Northwestern University)	PHOSPHORS 2 Partha Dutta (RPI)
1:45 PM	CATALYSTS Short presentations, dialog and discussion Gallery 1 Facilitator: Shum, Karma Rapporteur: Chetna Khosla ARPA-E Notes: Rusty, Aron	PHOSPHORS Short presentations, dialog and discussion Gallery 3 Facilitator: Dave Danielson Rapporteur: Jim Horwitz ARPA-E Notes: Phil, Nick
2:00 PM		
2:15 PM		
2:30 PM		
2:45 PM		
3:00 PM	Break	
3:15 PM		
3:30 PM	Report Out Gallery 2	
3:45 PM		
4:00 PM		
4:15 PM		
4:30 PM	Conclusion of Day Mark Johnson	
4:45 PM	"No Host" Happy Hour / Dinner (Hotel Bar) Sidebar Discussions with ARPA-E Program Director (On Request)	
5:00 PM		

Ground Rules

- "A consensus means that everyone agrees to say collectively what no one believes individually."
  – Abba Evan
  - The Goal is NOT Consensus
- "A *revolutionary idea* is usually one with its sleeves rolled up."
  - Navjot Singh Sidhu
  - The Focus is on Revolutionary NOT Evolutionary
- "Every Great Oak is just a Nut that held its Ground."
  - Anonymous
  - ALL Ideas are Welcome

Logistics

- Bathrooms
- Internet / Cell phone service
- Dinner / Happy Hour
  - Starts 5pm in the Hotel Restaurant
- One-on-one discussions / sign-up
  - Starts at 5:45 in the Hotel restaurant