CMI | Accelerating Energy Innovations

Critical Materials Institute

AN ENERGY INNOVATION HUB

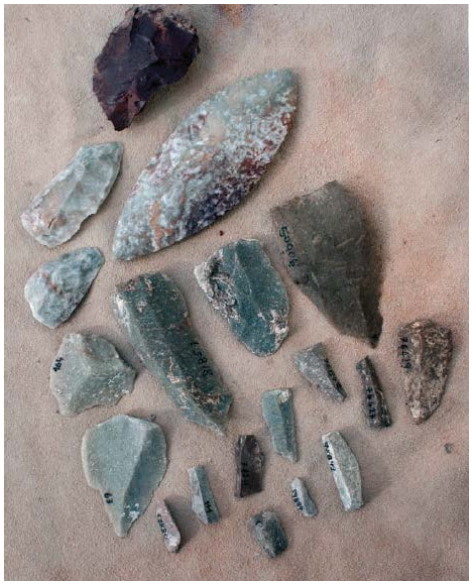
Focus Area #1: Diversifying Supply

Bruce A. Moyer (ORNL), Lead

R. Scott Herbst (INL), Deputy Lead

Are critical materials a recent problem?

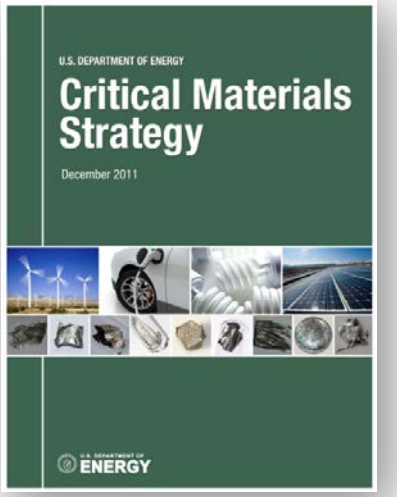
- Climate change starting 195,000 years ago brought the population of our human ancestors down to a population of a few hundred along the coast of south Africa.
- Stone materials suitable for flaking appear to have been in short supply or nonexistent in this region.
- Silcrete, a fine-grained quartz material of local origin was not a suitable material.



CW Marean, et al. 2010

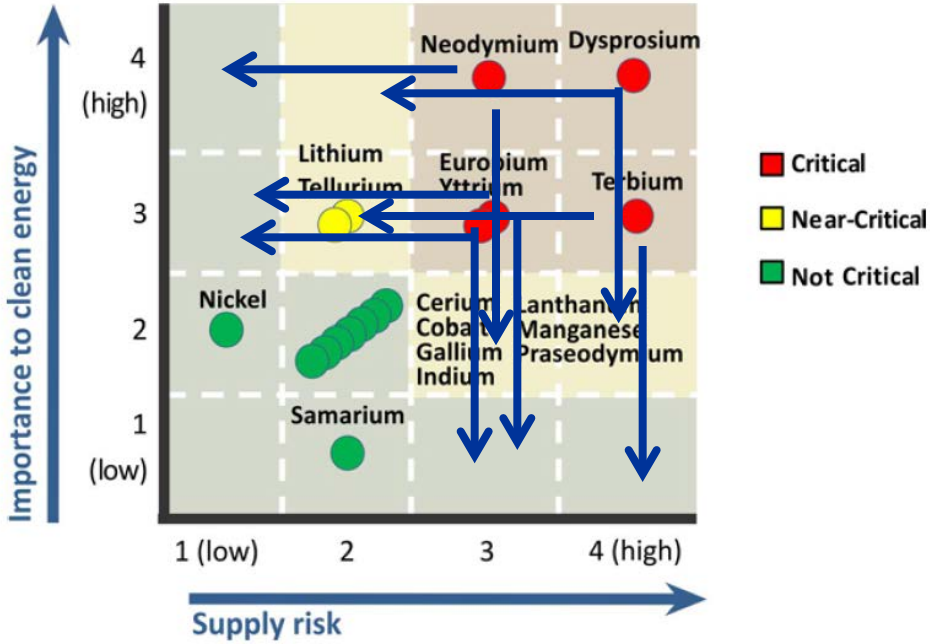
- Invention of a pyrotechnology applied to silcrete made it possible to flake this material for the manufacture of stone implements such as spear points 71,000–164,000 years ago.

Critical materials for clean energy were found by DOE to involve five rare earth elements*



***Each industry has its own set of critical materials**

Medium term 2015–2025



Taken from Figure ES-2 of the 2011 DOE Critical Materials Strategy document

Critical:

Nd and Dy for magnets
Eu, Tb, and Y for phosphors

Near Critical:

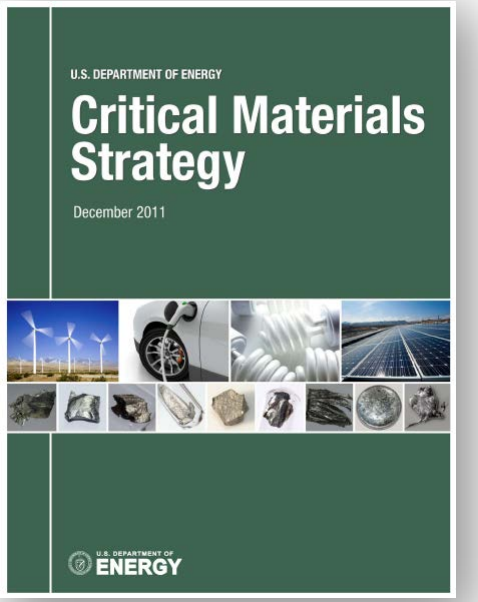
Li for energy storage
Te for photovoltaics

CMI goal: OUT OF THE BOX
by thinking OUT OF THE BOX

The Diversifying Supply Focus Area seeks to increase and stabilize the global supply of critical materials

Goal

Eliminate dependence on critical materials for clean energy by diversifying the global supply chain.



Desired outcome

Effectively increased supply
Greater diversity of sources
Better technology options

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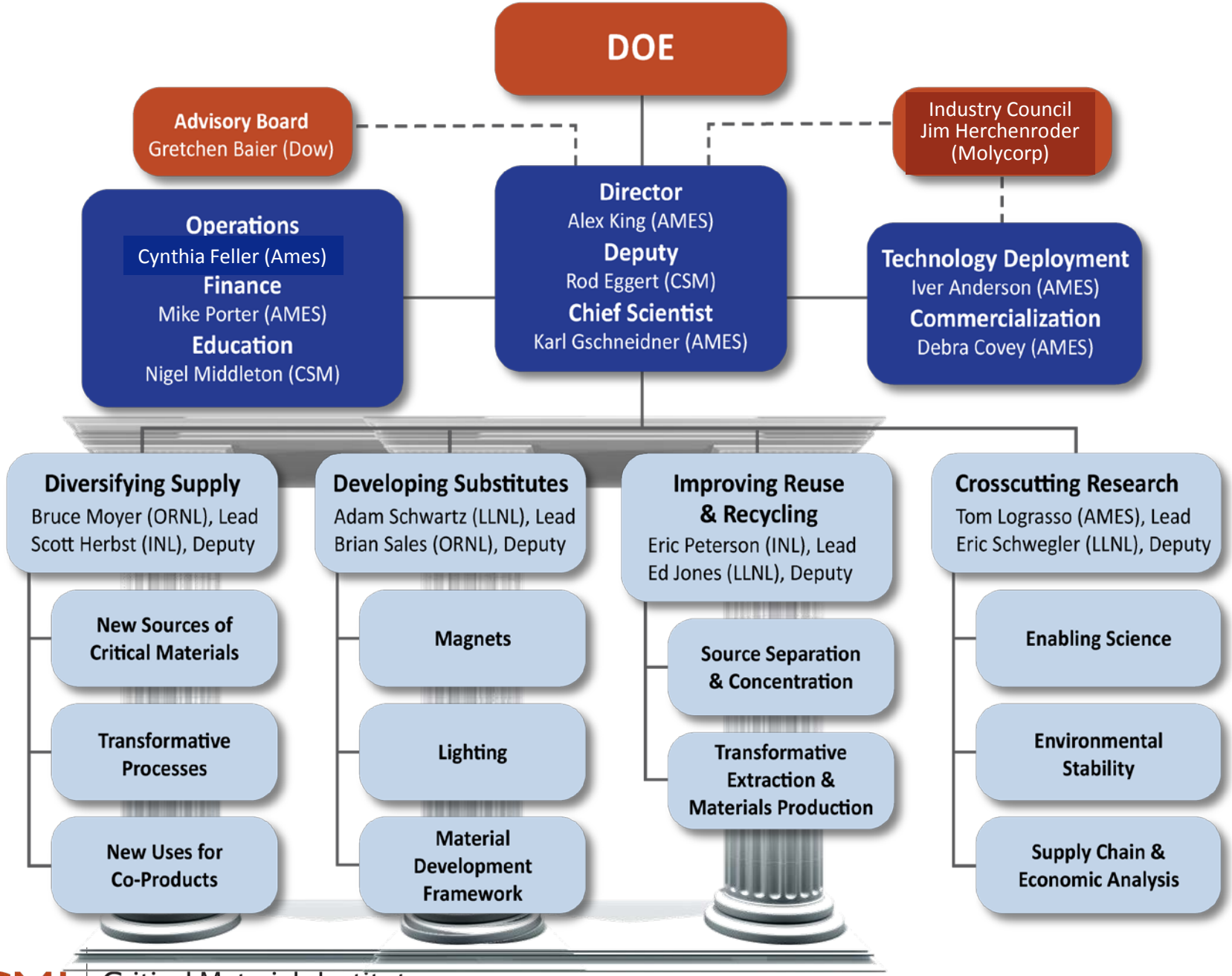
More favorable economics
Greater stability of supply
Competitive US industry



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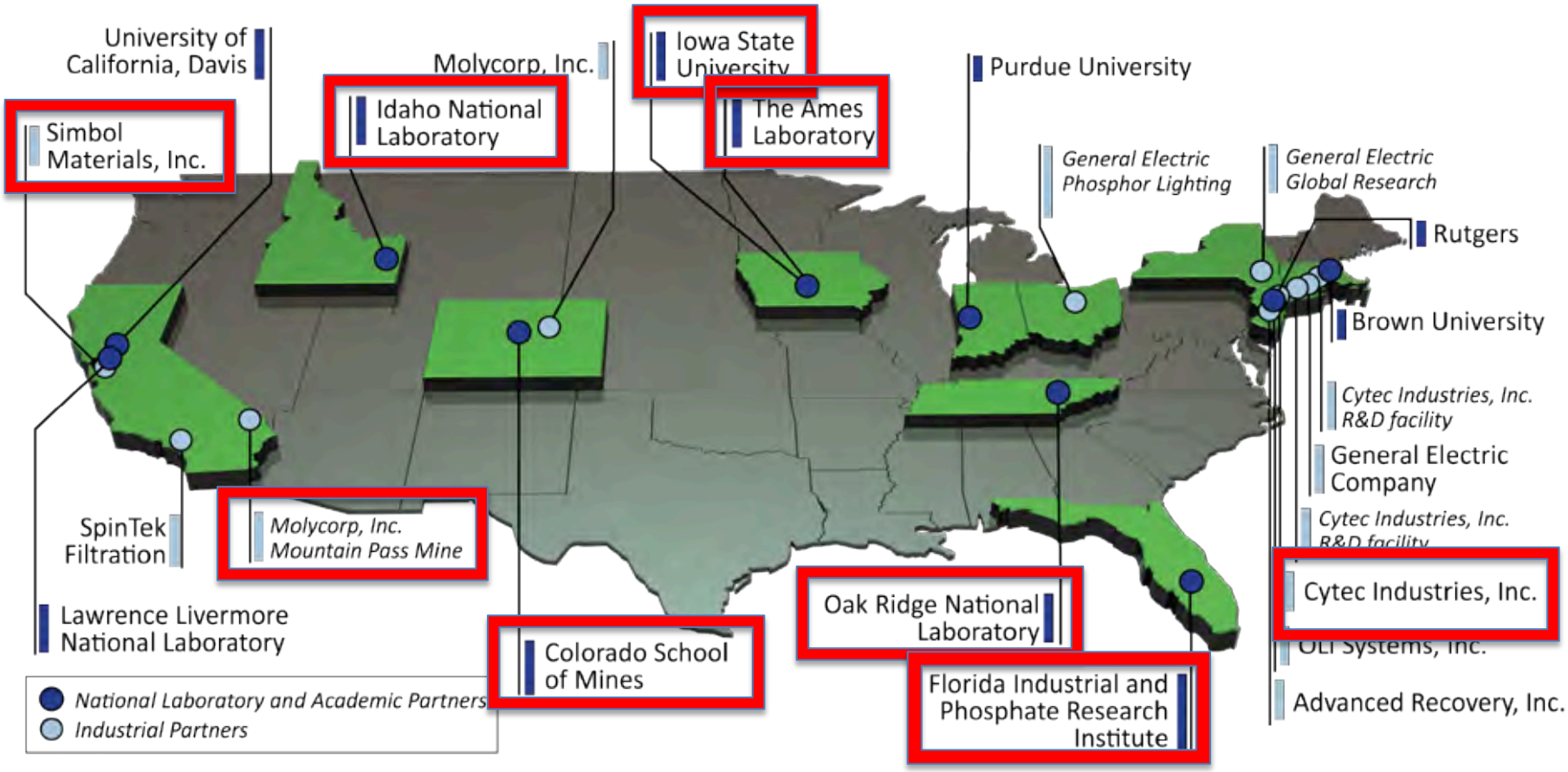
One Integrated Team

Focus Area 1



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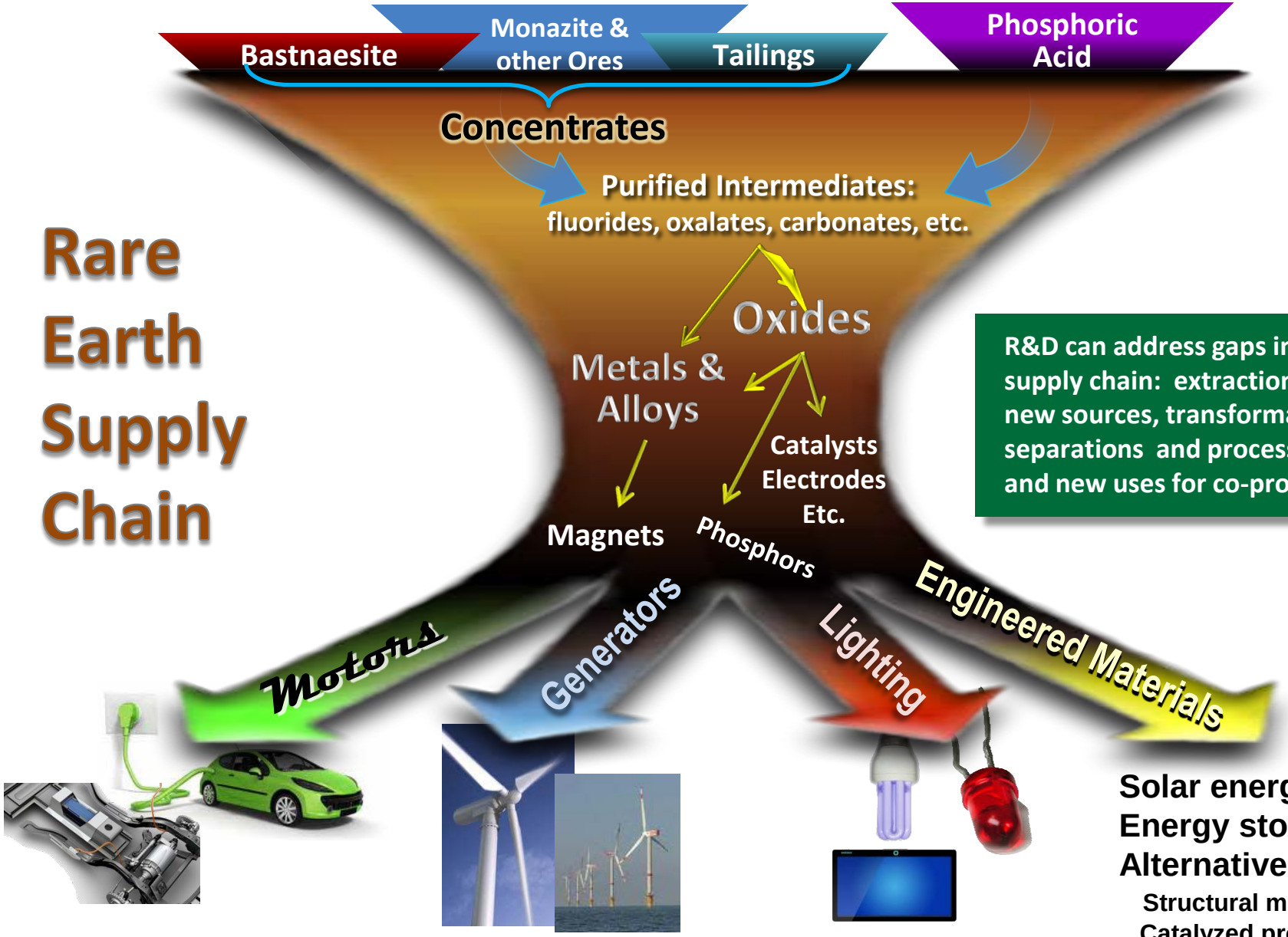
Why do we need to diversify the supply of CMs?

- **We currently rely on a single RE mineral**
  - **Bastnaesite is major source being processed, mostly in China**
  - **As a fluorocarbonate, it can be "cracked"**
  - **Bastnaesite is lean in the critical REs Eu, Tb, Dy, and Y**
- **Numerous sources are underutilized**
  - **Monazite in Molycorp ore can enhance production up to ~25%**
  - **Other ore bodies can add HREs**
  - **REs in phosphate ore equivalent to supply of RE ore**
  - **Tailings from mineral processing are a potentially vast supply**
- **Separations and conversion to metal done outside US**
- **La and Ce are underutilized**
- **Rising demand for lithium will challenge supply**

Rare Earth Supply Chain



R&D can address gaps in this supply chain: extraction from new sources, transformational separations and processes, and new uses for co-products

Solar energy
Energy storage
Alternative uses
- Structural materials
- Catalyzed processes

CLEAN ENERGY TECHNOLOGIES

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What are the technology gaps in processing the critical rare earths?

- Extraction technologies are costly—most developed for bastnaesite
- Selectivity in the concentration step is difficult
- Uranium, thorium, and daughters present an environmental issue but an opportunity
- Separation of adjacent lanthanides is very inefficient—low separation factors
- Conversion of oxides to metals and alloys requires extreme conditions and pollutes

Three thrusts will be pursued to address the gaps in the supply chain and to fulfill life-cycle imperatives

- **New sources of critical materials**

  Develop efficient and environmentally benign technologies for beneficiation, separation, and purification

- **Transformational processes**

  Dramatically increase processing efficiency to eliminate bottlenecks in the supply chain, reduce cost, and minimize environmental impact

- **New uses**

  Develop new uses for, or enhanced usage of, co-products that benefit overall supply-chain economics

The New Sources Thrust will enable sources of supply that are currently not economical

New Sources Projects

- **Advanced beneficiation techniques (CSM, ORNL, Molycorp, Cytec)**
  Develop advanced beneficiation techniques applicable to REE ores and tailings
  Enables subsequent separations by concentrating target minerals

- **Recovery of REEs and U from phosphate (ORNL, INL, Cytec, FIPR)**
  Develop new separations that enable vast REE supply as phosphate by-products
  REEs and U in phosphate ore, phosphogypsum tailings, and phosphoric acid product

- **Recovery of Lithium (Simbol, ORNL)**
  Develop improved sorbents, membranes, and extractants for Li recovery from brine

The Transformational Separations Thrust will dramatically improve the economics of processing critical materials

Transformational Separations Projects

- **Adjacent lanthanide separations (INL, ORNL, Molycorp, Cytec)**
  Increase the separation factor among REEs, especially adjacent lanthanides
  Solving this classical problem will dramatically lower separation costs
- **Conversion of metal oxide to metal, alloys, and materials (CSM, ORNL, Ames, Cytec, Molycorp)**
  Improve upon obsolete and environmentally unacceptable processes
  Better processes will be more attractive to US industry
- **Ionic-liquid based separations processes (ORNL, Cytec)**
  Develop separations and processes by exploiting novel properties of ionic liquids
  Breakthrough combined dissolution/separation/electroreduction at low T
- **Compuational prescreening of ligands (Ames, ORNL, Cytec)**
  Improve computational methodology to speed time to new separation-agent design
  Demonstrate 5 times faster time to solution

The New Uses Thrust will find new uses for co- and by-products that currently do not contribute to the economics of critical-materials production

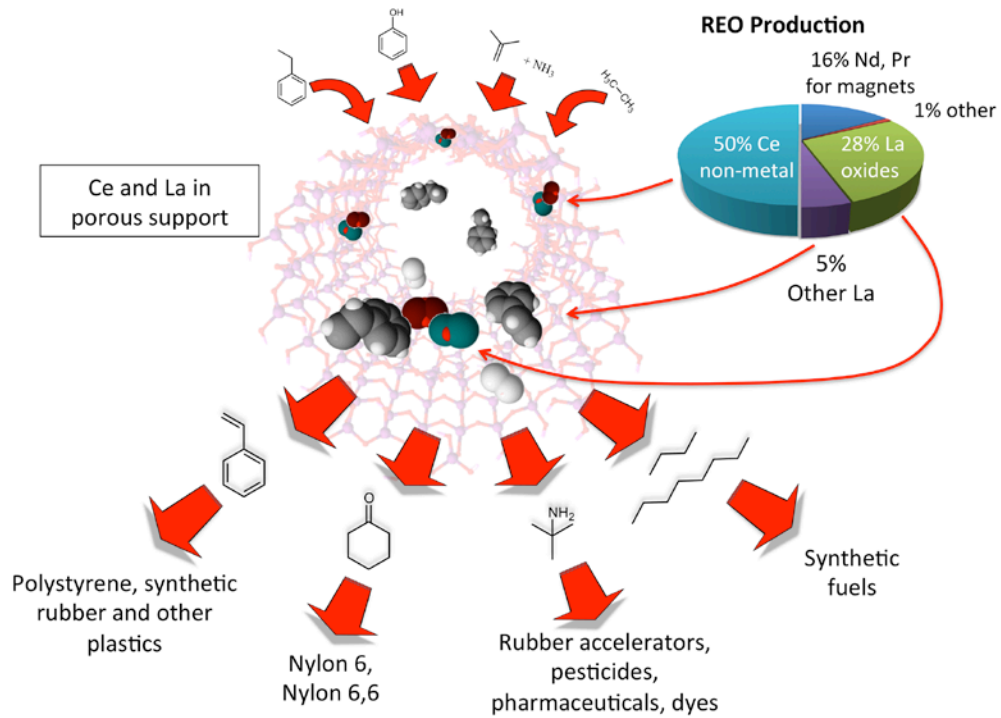
New Uses Project

New lanthanide-based catalysts (Ames, ORNL, Dow)

Develop new catalysts using La and Ce for large-scale chemical processes

Increasing the market for LREEs will decrease cost of producing the critical REEs

Products from catalyzed conversions



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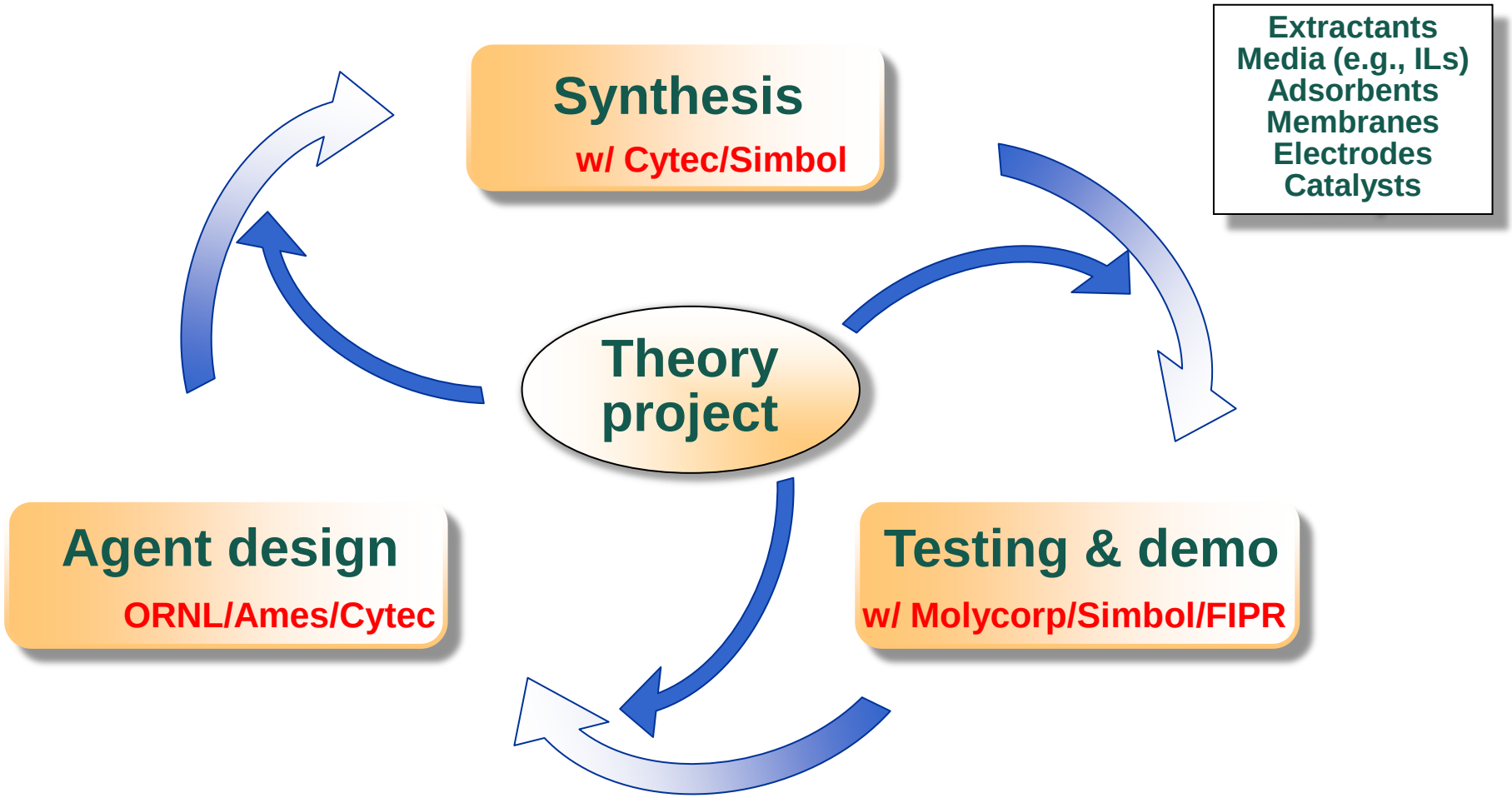
Material development cycle illustrates role of industry and theory



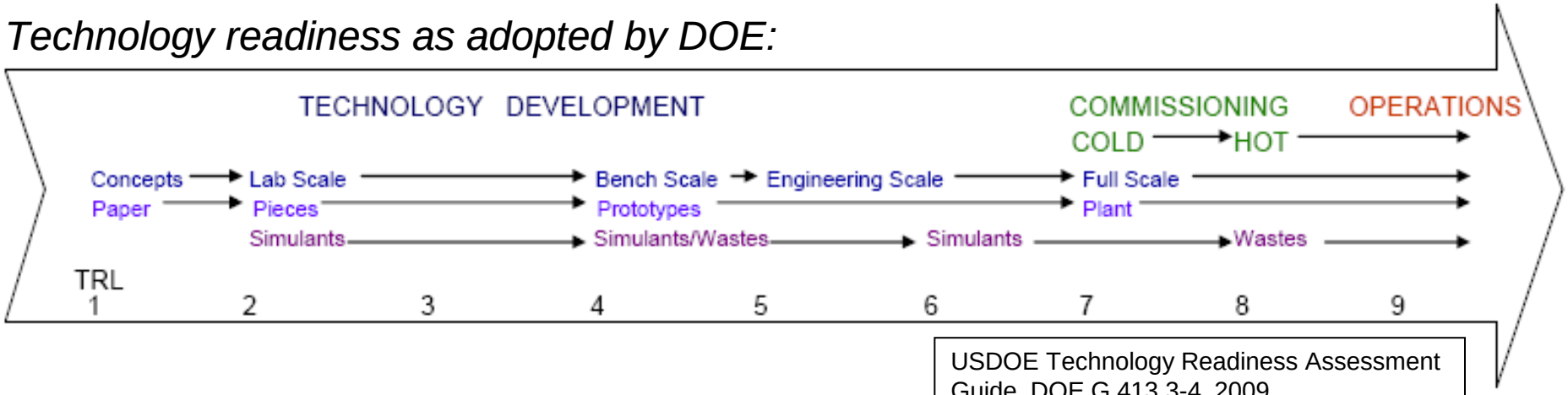
Vision of partnering with industry

- **Industry involved in early planning of CMI projects**
- **Ideally, establish a mutual plan, not just CMI plan**
- **Progress reports and highlights provided to partner down to the project level**
- **Partner's progress communicated to CMI**
- **Partner notified of relevant CMI inventions in accord with IP plan**
- **Annual CMI review**
- **Sensitivity to IP and publication issues on both sides**

A phased approach leads to technology maturation and likely commercialization

- **Initial technology maturation level 2–3**
- **Industrial partners advise projects in initial phases**
- **Progress to TRL 4–6**
- **Industrial partner begins active role in development and demonstration phases**
- **Success = commercialization/deployment**

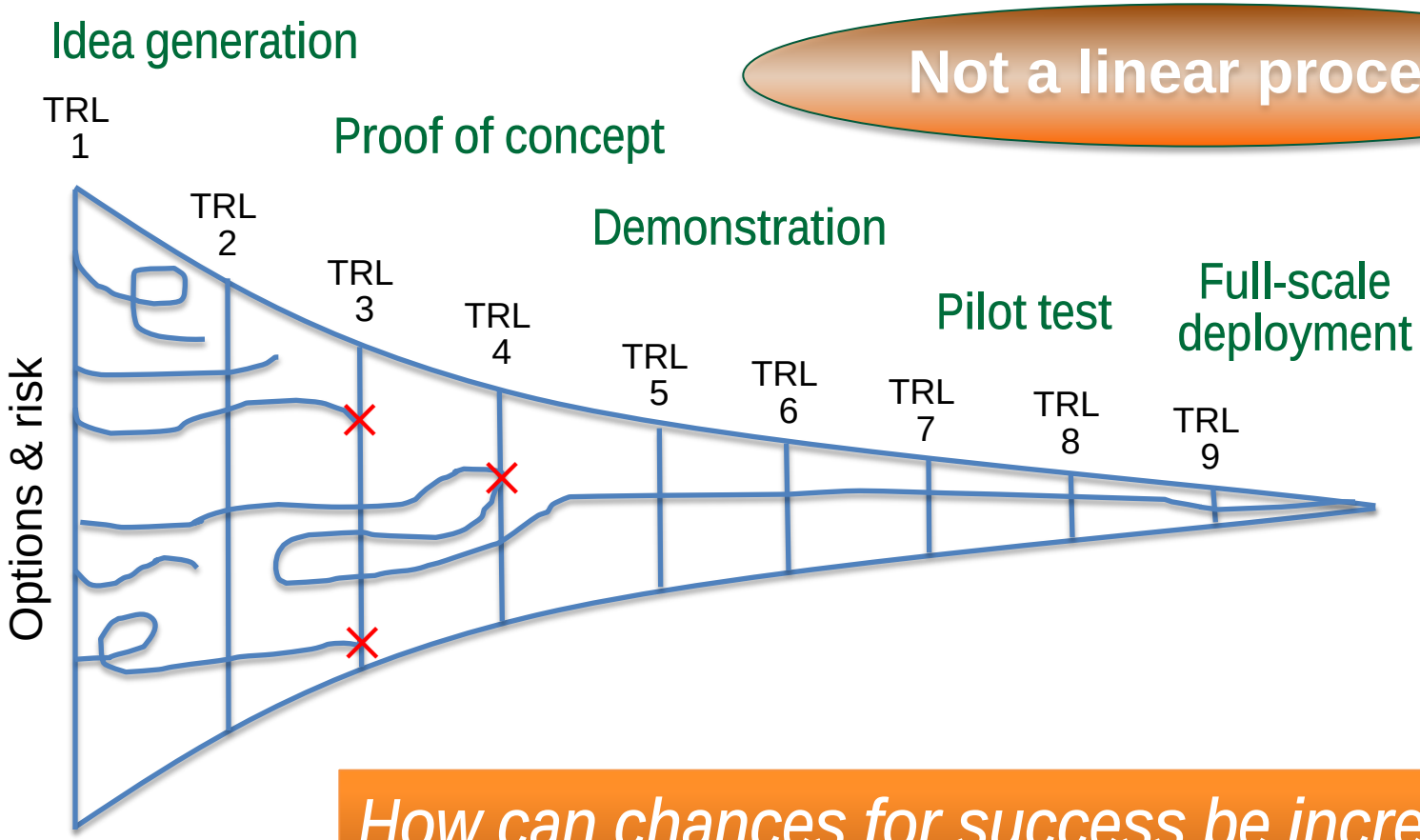
Technology readiness as adopted by DOE:



USDOE Technology Readiness Assessment Guide, DOE G 413.3-4, 2009.

Concepts will progress through a tortuous (or torturous?) testing with a high chance of failure

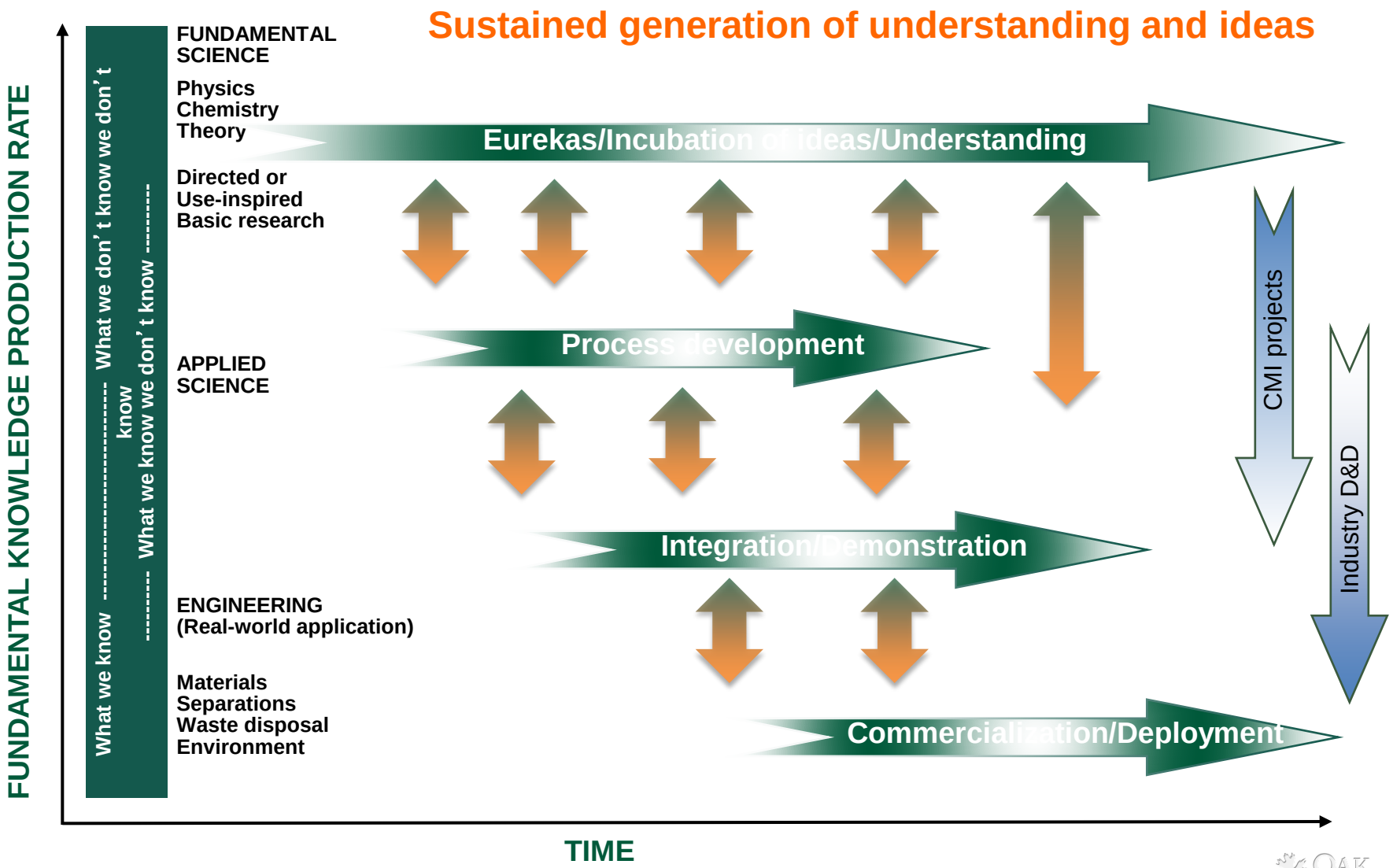
Not a linear process



How can chances for success be increased?

B. A. Moyer, unpublished

Two-way interactions occur as technologies mature



B. A. Moyer, unpublished

Projects are expected to support diversification of supply

Each project:

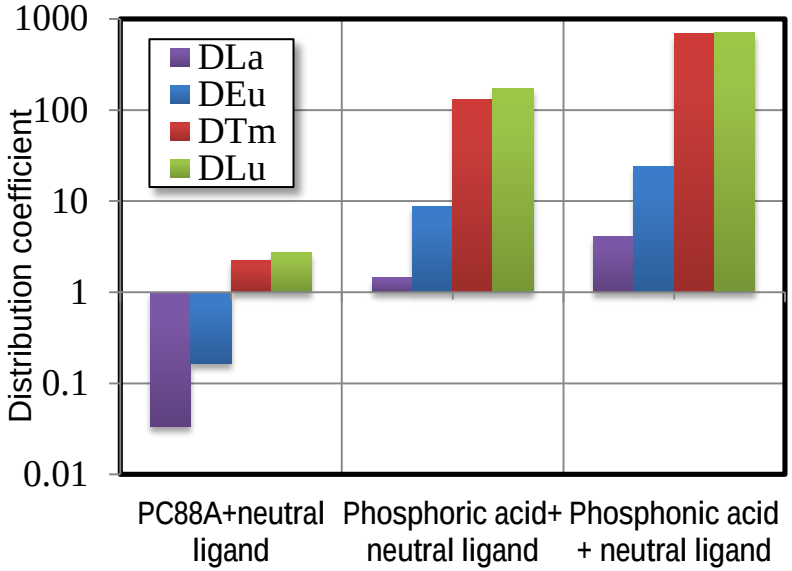
- **Helps to build generic supply-chain capability**
  Beneficiation, extraction, separation, conversion, molecular design
- **Has high impact on CM or near-CM supply**
  Nd, Eu, Tb, Dy, Y and Li, Te, La, Ce
- **Addresses key technical challenges or gaps in CM supply**
  New sources, transformational processing, new uses
- **Has good commercialization pathway**
- **Is likely to succeed (technical scope, PI qualification, etc.)**

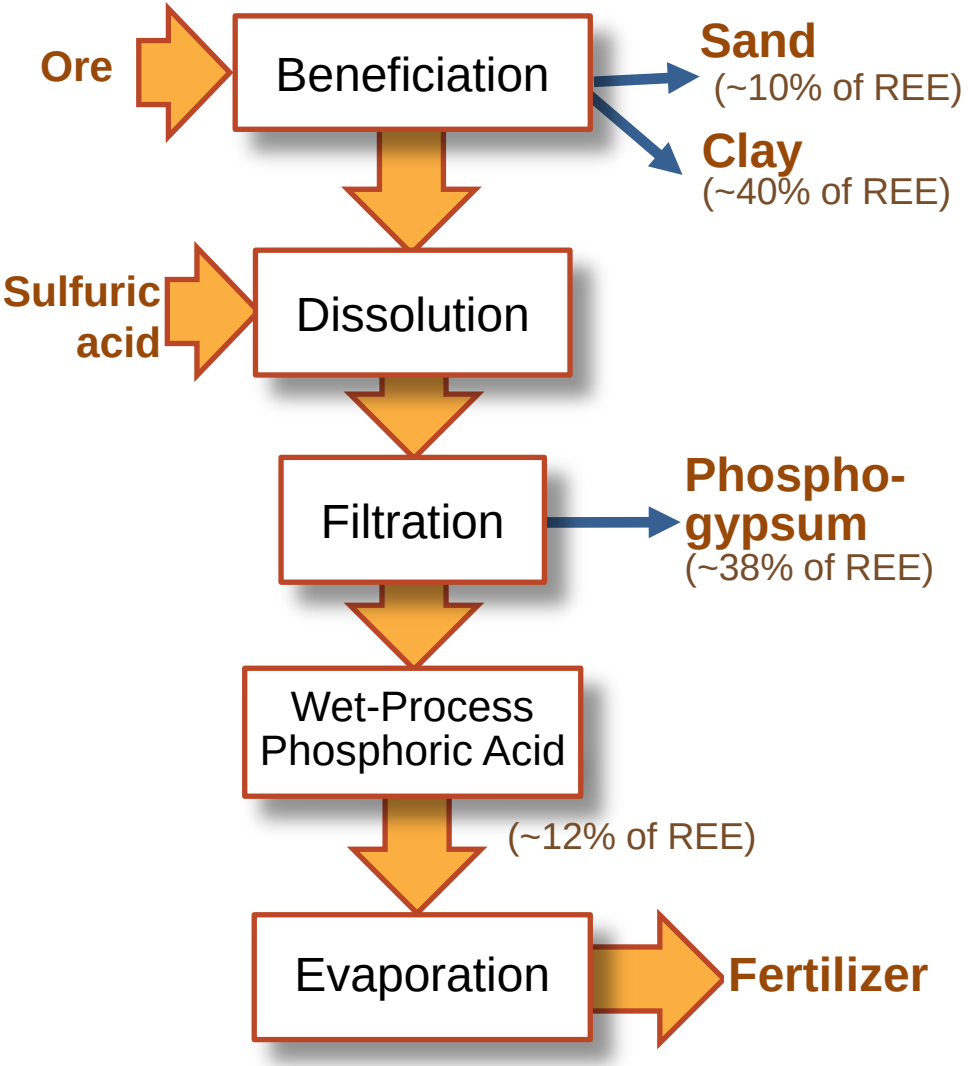
Recovery of REEs and U from Phosphate Ore Project taps into potentially vast REE supply (ORNL, INL, FIPR, Cytec)

28.4 million metric tons of phosphate rock are produced per year in the US, containing approximately

- 2500 MT each of Nd and Y
- 200-300 MT each of Dy and Eu
- 40 MT of Tb

Extraction of 4 lanthanides from industrial phosphoric acid sample from FIPR

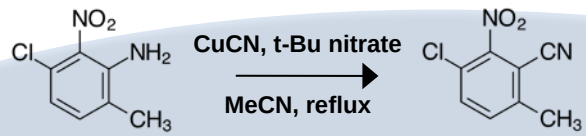




New technology will transform separation of individual REE (INL, ORNL, Cytec, Molycorp)

Challenge: Slight differences between the ionic radii of adjacent lanthanides make them extraordinarily hard to separate

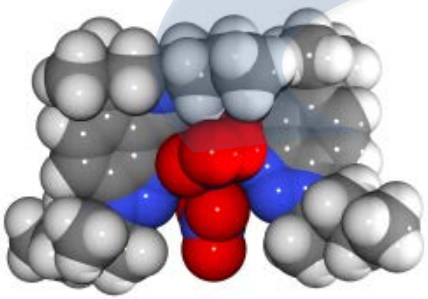
Opportunity: Preorganized extractants could dramatically improve the economics of producing pure REE (esp. Nd, Tb, Dy, Y)



Design

Synthesis

Testing



Lanthanide complex with computationally designed extractant molecule

CYTEC

Molycorp

Commercialized new extractants and processes

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SX Pilot Plant – Mixer Settlers

- 30 Stages of mixer settler units
- Total throughput (O+A) ~1.5 – 2 Lpm with high turndown ratios
- Components compatible with Cl, NO_3, PO_4, SO_4 media
- Rapid development and testing of flowsheets with new extractant systems

Lithium recovery project aims to increase lithium supply to meet growing demand

Simbol, ORNL

Reserves of Li can supply new demand

Improved separation agents for recovery of of LiCl from Salton Sea geothermal brine

- **High-capacity sorbent materials**
- **High-throughput membranes**

Improved methods for concentration of LiCl

Improved membranes for converting LiCl to LiOH

Simbol facilities in Pleasanton, Brawley (demo plant at right), and Calipatria, CA

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SIMBOL materials

Ionic-liquid based separations project aims for transformational improvement in processing

ORNL, Ames, Cytec, Molycorp

Major advance is possible by combining processes

- **Dissolution**
- **Liquid-liquid separation**
- **Coupling with electro-chemical methods**

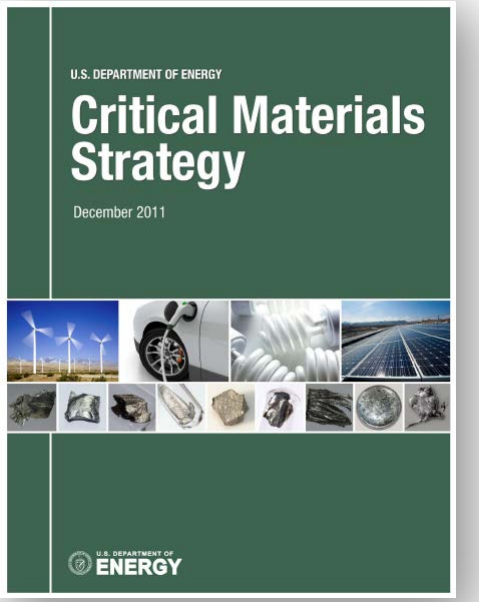
Dissolution of Molycorp bastnaesite c

Focus Area #1 plan lays a strong foundation for success

Strong plan designed to achieve goal

Eliminate dependence on critical materials for clean energy by diversifying the global supply chain.

Three thrusts target multiple opportunities, address lifecycle imperatives



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