Global Energy Future Initiative

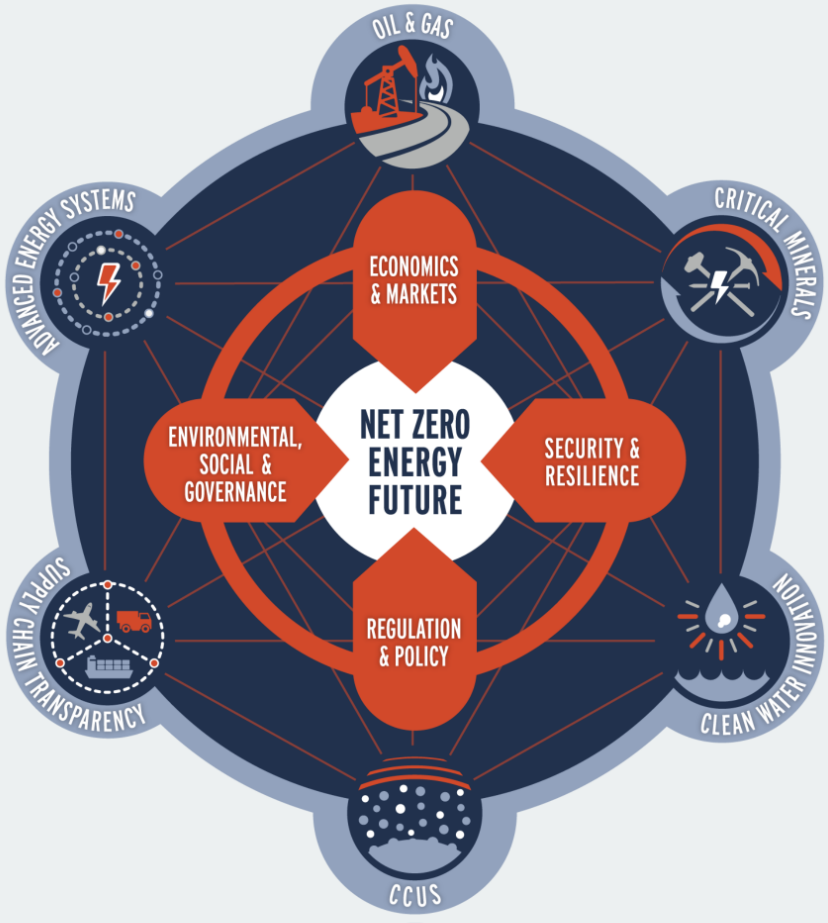
Meeting the Net Zero Challenge

COLORADO SCHOOL OF MINES

global@mines.edu

What impact do we want to make?

Why it matters?



How can we create a sustainable energy future?

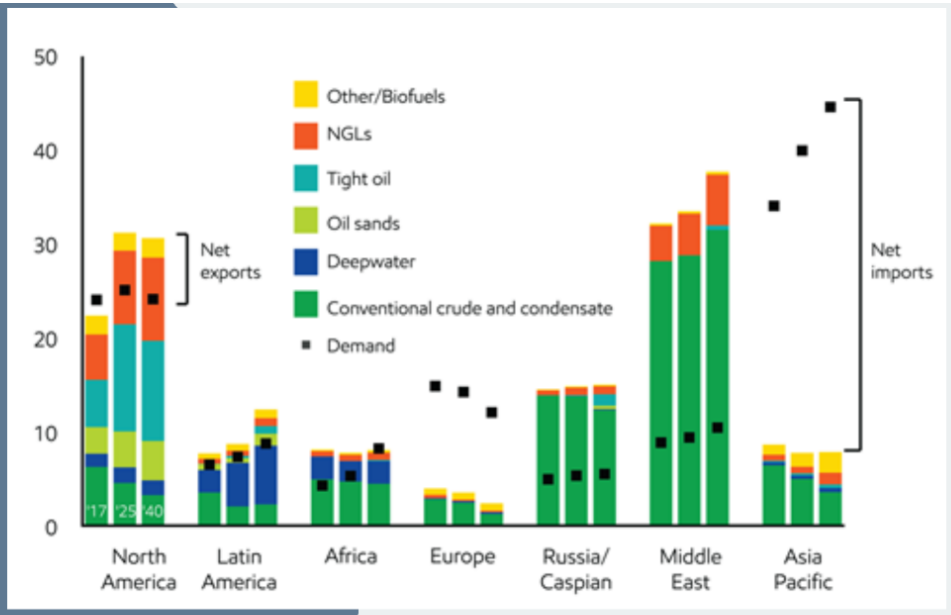
- Our energy future needs:
  - Energy demands to power a growing, global population
  - Sustainable
  - Limit environmental and social impact
- The Grand Challenge: Net zero carbon emissions

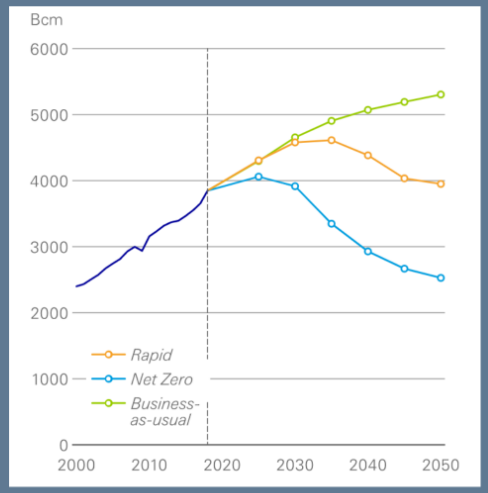
“The rise in US production of tight oil and shale gas since 2010 is the largest parallel increase in oil and gas output in history”

International Energy Agency, World Energy Outlook, 2018

Growth of Liquid Fuel Supply by Region

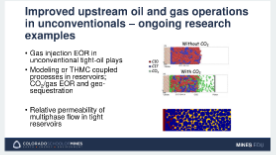
ExxonMobil 2020 Energy Outlook





Gas Consumption

BP 2020 Energy Outlook



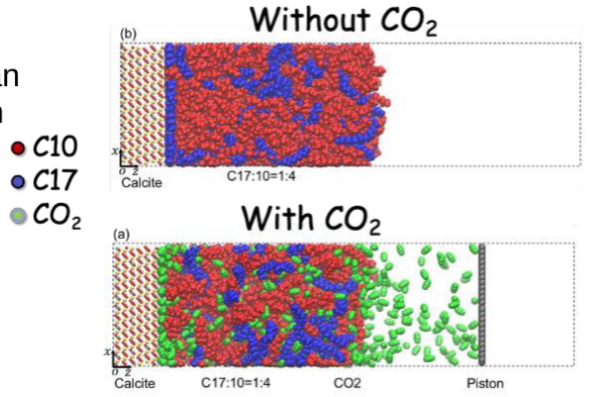
Improved upstream oil and gas operations in unconventionals – ongoing research examples

- Gas injection EOR in unconventional tight-oil plays

Erdal Ozkan
Xialong Yin

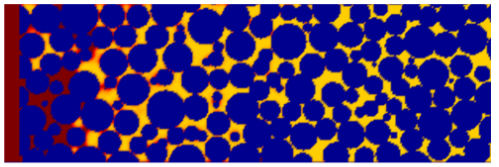
- Modeling or THMC coupled processes in reservoirs; CO_2/gas EOR and geo-sequestration

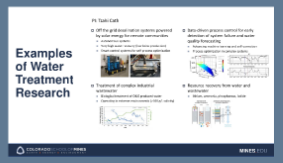
Yu-Shu Wu



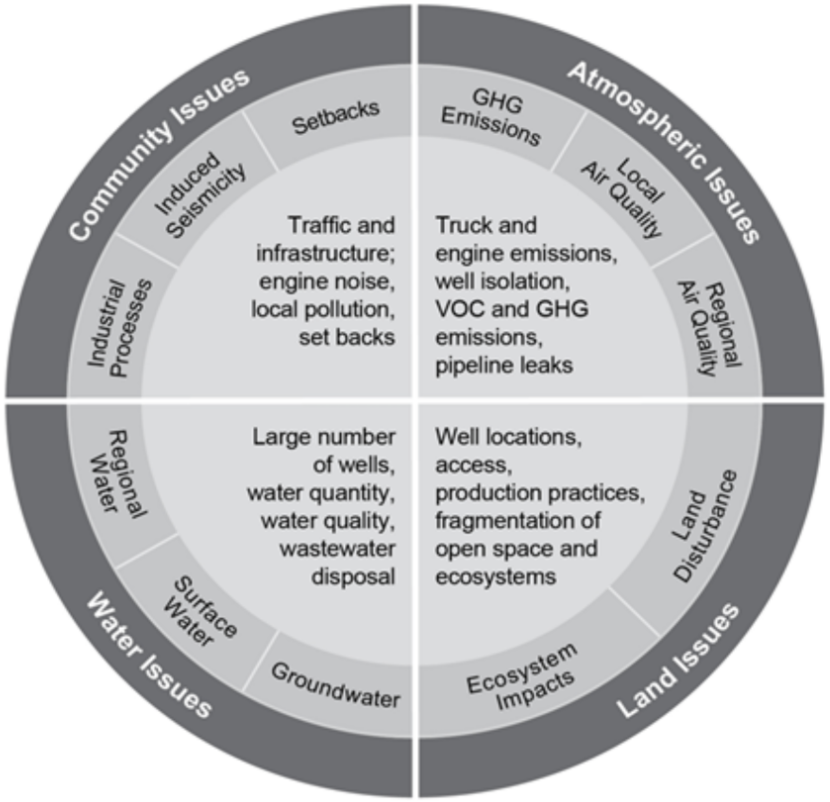
- Relative permeability of multiphase flow in tight reservoirs

Xialong Yin





Risk Factors

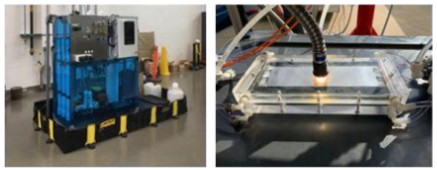


Zoback and Arent, 2014, The Bridge

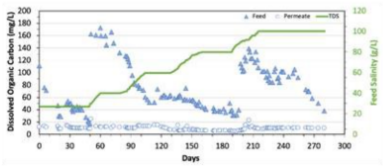
Examples of Water Treatment Research

PI: Tzahi Cath

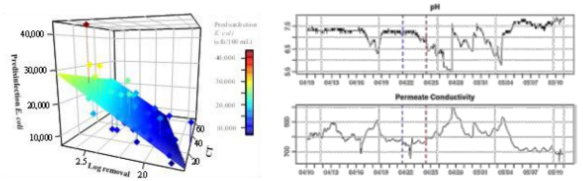
- Off the grid desalination systems powered by solar energy for remote communities
  - Autonomous systems
  - Very high water recovery (low brine production)
  - Smart control systems for self process optimization



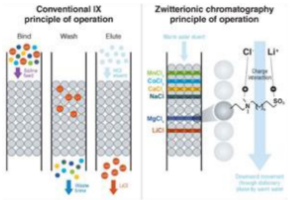
- Treatment of complex industrial wastewater
  - Biological treatment of O&G produced water
  - Operating in extreme environments (>100 g/L salinity)

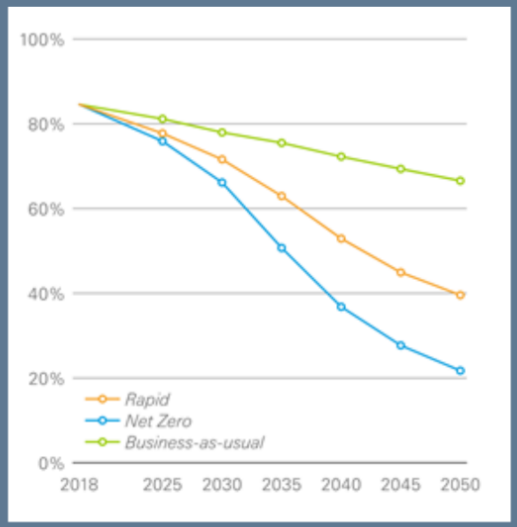


- Data-driven process control for early detection of system failure and water quality forecasting
  - Advancing machine learning and self-correction
  - Process optimization in complex systems



- Resource recovery from water and wastewater
  - lithium, ammonia, phosphorous, iodide





Oil and Gas Demand
BP 2020 Energy Outlook

2040 Energy Mix
ExxonMobil 2020
Energy Outlook

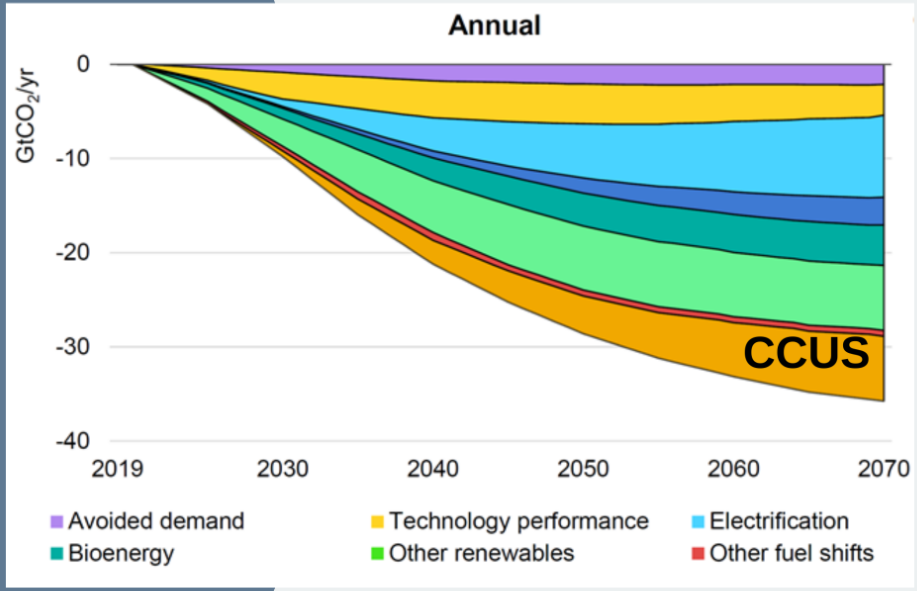
“The risk of climate change is clear and the risk warrants action. Increasing carbon emissions in the atmosphere are having a warming effect.”

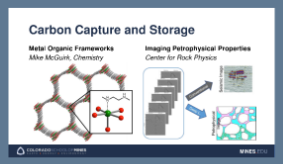
“We know enough based on the research and science that the risk is real and appropriate steps should be taken to address that risk.”

ExxonMobil

Reaching net zero will be virtually impossible without CCUS (2020 IEA Special Report on CCUS)

NAE Grand Challenge

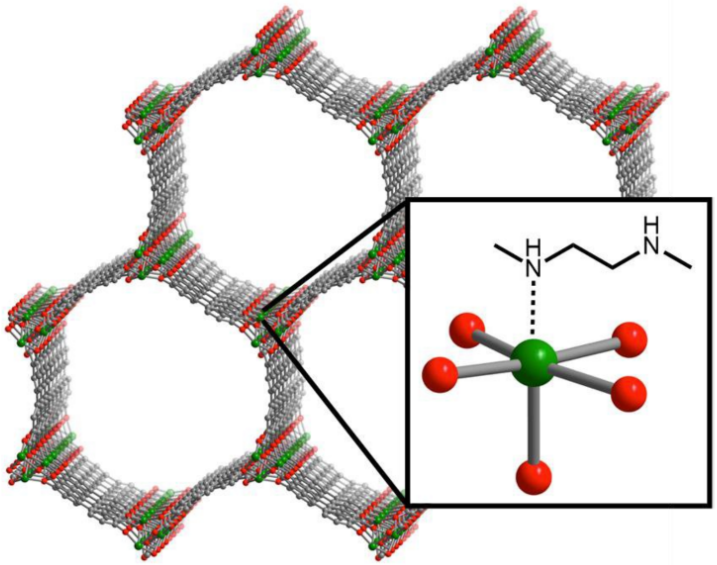




Carbon Capture and Storage

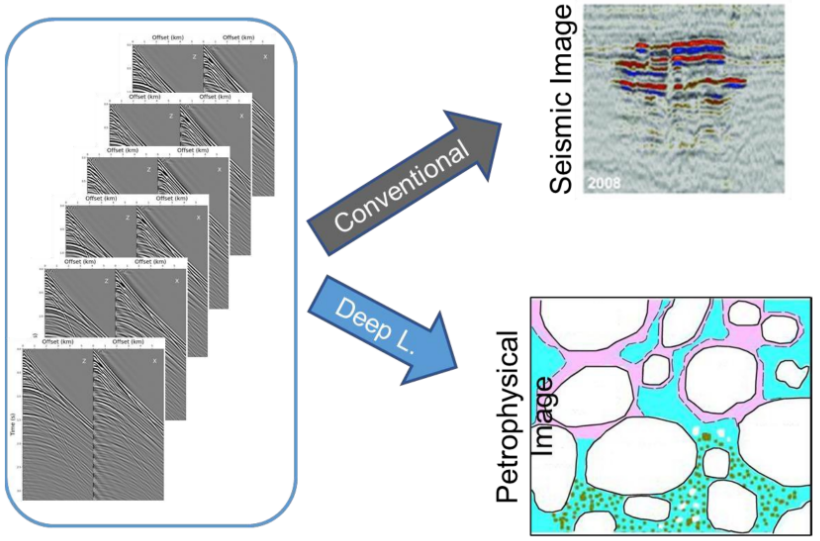
Metal Organic Frameworks

Mike McGuirk, Chemistry

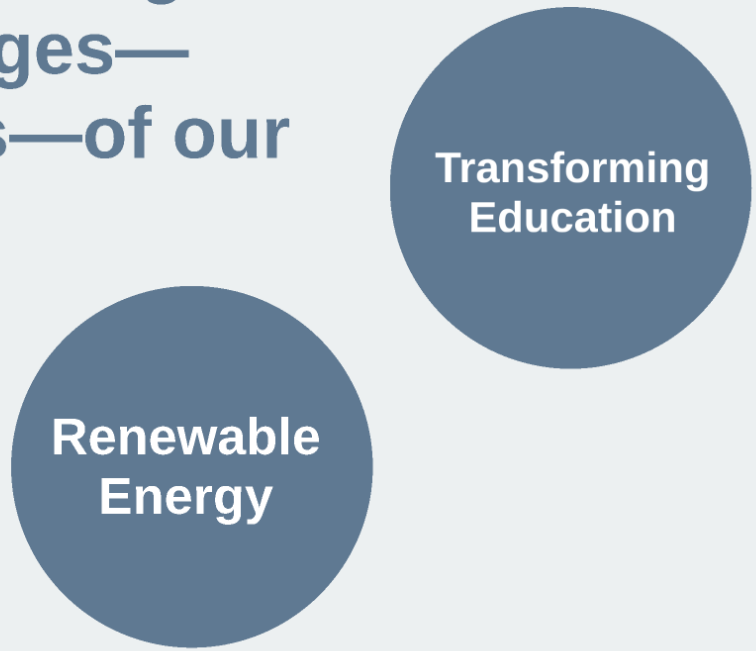


Imaging Petrophysical Properties

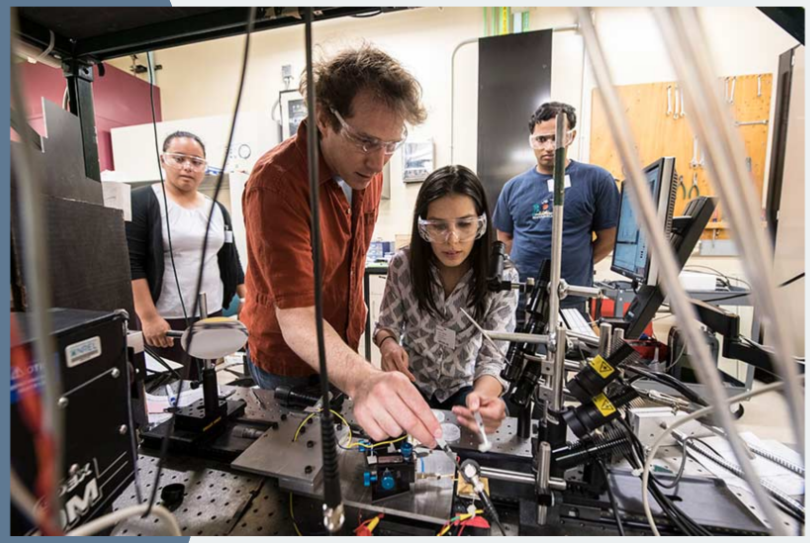
Center for Rock Physics



Developing sustainable energy infrastructure that fosters economic growth while reducing environmental impact is among the most pressing challenges—and greatest opportunities—of our time

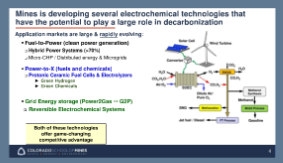


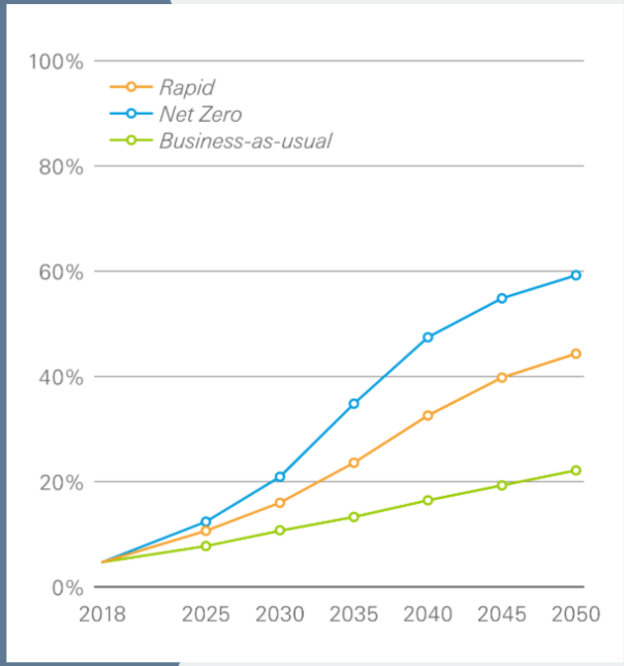
Mines and National Renewable Energy Laboratory are partnering on the Advanced Energy Systems PhD and MS Programs focused on developing future energy thought leaders.



Shares of Primary Energy: Renewables

2020 BP Energy Outlook

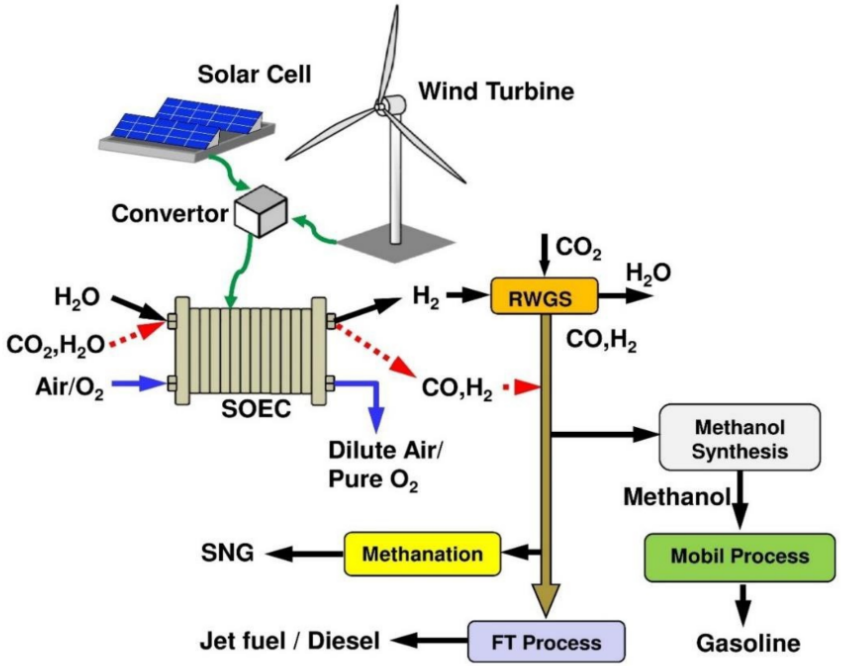




Mines is developing several electrochemical technologies that have the potential to play a large role in decarbonization

Application markets are large & rapidly evolving:

- **Fuel-to-Power (clean power generation)**
  - **Hybrid Power Systems (>70%)**
  - Micro-CHP / Distributed energy & Microgrids
- **Power-to-X (fuels and chemicals)**
  - **Protonic Ceramic Fuel Cells & Electrolyzers**
    - **Green Hydrogen**
    - **Green Chemicals**
- **Grid Energy storage (Power2Gas ↔ G2P)**
  - **Reversible Electrochemical Systems**



Both of these technologies offer game-changing competitive advantage

"[W]ind turbines, solar power stations and other facilities ... will require vast amounts of metals and other raw materials"

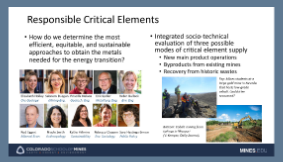
Vidal et al., 2013,
Nature Geoscience

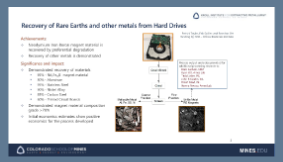
Metals and Minerals Demand Growth

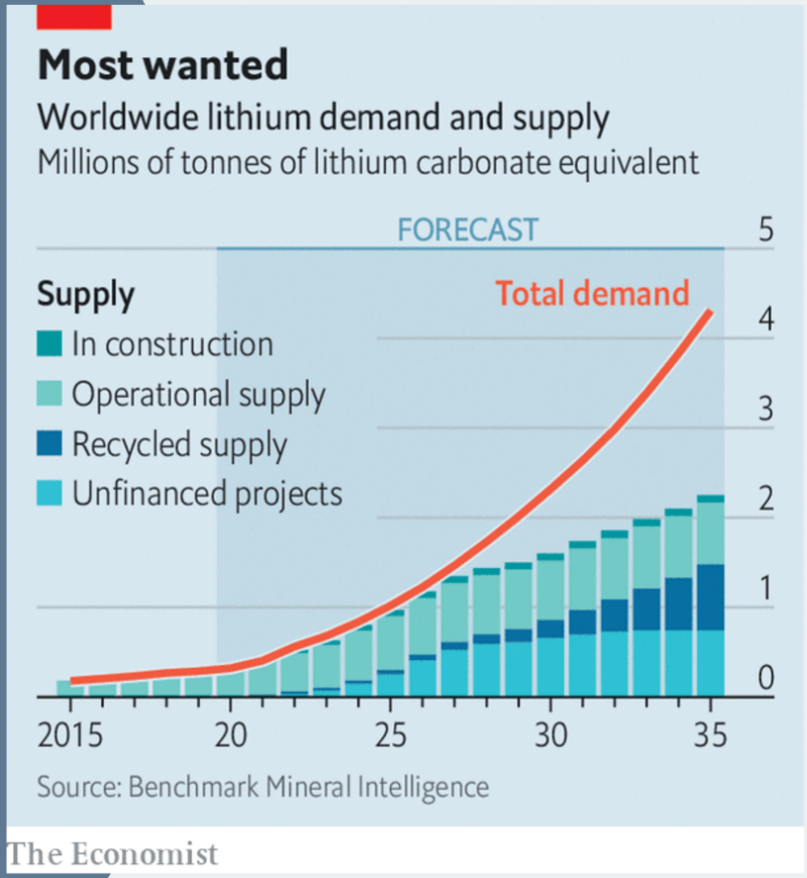
"A shift to renewable energy will replace one non-renewable resource (fossil fuel) with another (metals and minerals)."

Vidal et al., 2013,
Nature Geoscience

We must quickly transition to low carbon technologies for extraction of metals and minerals, while managing environmental and social impacts







Responsible Critical Elements

- How do we determine the most efficient, equitable, and sustainable approaches to obtain the metals needed for the energy transition?

Elizabeth Holley *Ore Geology* | Sebnem Duzgun. *Mining Eng.* | Priscilla Nelson *Geotech. Eng.* | Erik Spiller *Metallurg. Eng.* | Robin Bullock *Env. Eng*

Rod Eggert *Mineral Econ.* | Nicole Smith *Anthropology* | Kathy Hilimire *Sustainability* | Rebecca Clausen *Env. Sociology* | Sara Hastings-Simon *Public Policy*

- Integrated socio-technical evaluation of three possible modes of critical element supply
  - New main product operations
  - Byproducts from existing mines
  - Recovery from historic wastes

Top: Mines students at a large gold mine in Nevada that hosts low-grade cobalt. Could it be recovered?

Bottom: Cobalt mining from tailings in Missouri (V. Kemper, Daily Journal)

Recovery of Rare Earths and other metals from Hard Drives

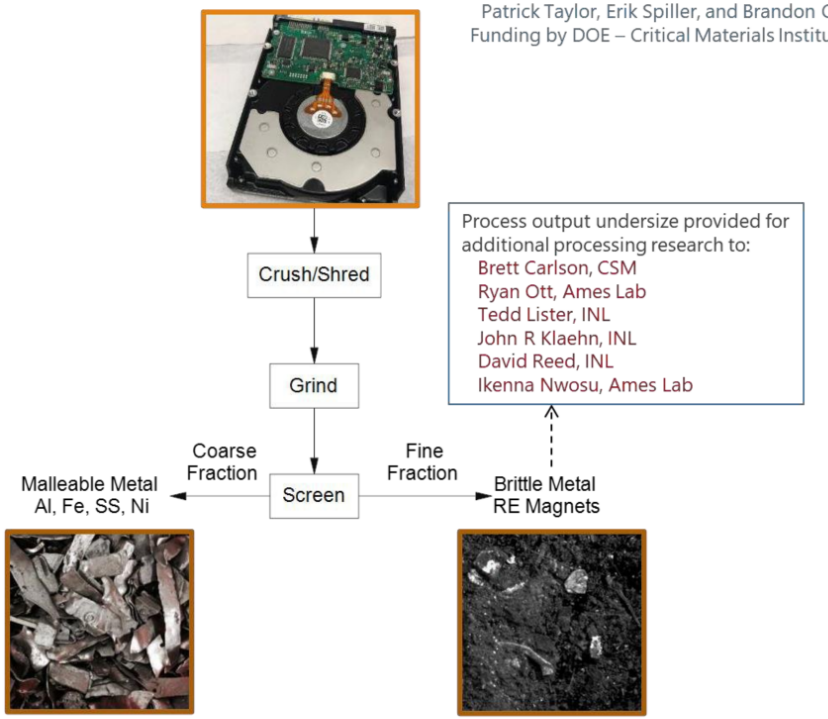
Patrick Taylor, Erik Spiller, and Brandon Ott
Funding by DOE – Critical Materials Institute

Achievements:

- Neodymium Iron Boron magnet material is recovered by preferential degradation
- Recovery of other metals is demonstrated

Significance and impact:

- Demonstrated recovery of materials
  - 95% - $Nd_2Fe_{14}B$ magnet material
  - 80% - Aluminum
  - 95% - Stainless Steel
  - 90% - Nickel Alloy
  - 85% - Carbon Steel
  - 60% - Printed Circuit Boards
- Demonstrated magnet material composition grade >70%
- Initial economics estimates show positive economics for the process developed



What are Mines goals?

- Mines develops and trains the leaders that will create the Global Energy Future
- Mines creates and demonstrates sustainable solutions for CCUS at relevant scale
- Mines is a source of solutions to responsibly meet the metals and mineral demand
- Mines creates technology solutions to meet the needs for continued growth of unconventional O&G while eliminating GHG emissions
- Mines creates alternative and renewable energy solutions.
- Mines is a source of economic solutions and supporting policy for the global energy future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SEPTEMBER 29, 2020 / BY EMILIE RUSCH
Colorado School of Mines ranked among nation's elite energy universities
The American Energy Society recognized Mines for "excellence in all fields, from fossil to sustainable materials and renewable energy"

CCUS at scale

- Mines CCUS Innovation Center
  - Interdisciplinary RTT Research Center involving twelve departments
  - Biannual CCUS Expo
- Fully online educational program
  - Short courses, graduate certificate, MSNT
- Mines Integrated CCUS Initiative
  - Payne Institute Seminar Series

We develop practical solutions to meet the global need for a carbon neutral energy system. We develop the leaders who will be required to meet this grand challenge.

Current Strengths

- Bio-capture
  - Upgrade to fuels and other products
- Capture Membranes
- Blue Hydrogen
- Geologic Storage and Monitoring
- Non-geologic Storage
- Carbon economics and policy

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Sustainable Oil and Gas

- Energy Data Science and Analytics Institute
  - Developing computational tools to utilize massive, diverse data, gain operational efficiency, and minimize environmental impact
- Partnership with Oil and Gas Climate Initiative
- CO2 EOR
  - Meeting demand for oil and gas while utilizing captured CO2 emissions

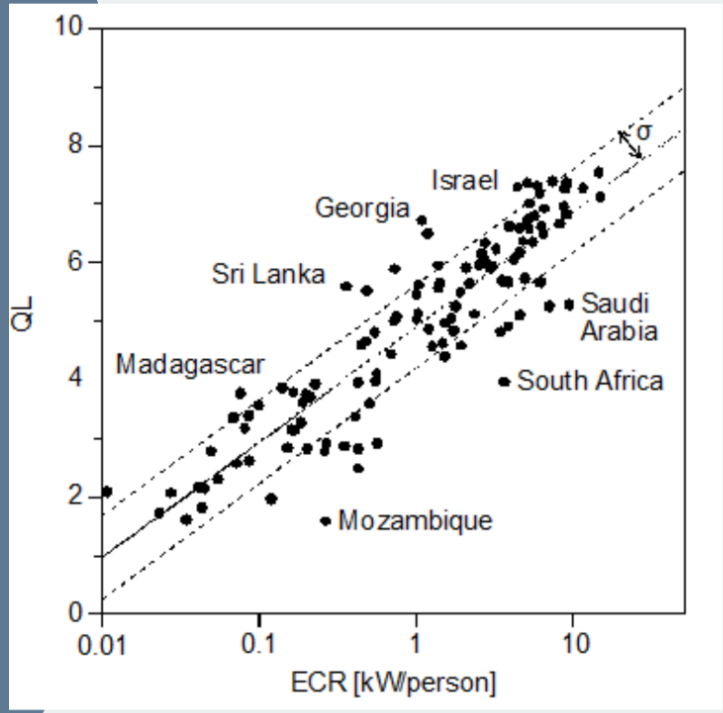
Energy Challenges

Impacts of climate warming will be significant and include risks to “health, livelihoods, food security, water supply, human security, and economic growth” (IPCC, 2018)

Transforming our energy system is among the most pressing challenges—and greatest opportunities—of our time

Mines is a leading HUB for energy education and research and can do more!

Quality of Life Correlates with Energy Use



Pasten and Santamarina, 2012

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