AI-Enabled Opportunities in Energy

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SLAC National Accelerator Laboratory

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The AI Summit San Francisco 2019

BOLD PEOPLE. VISIONARY SCIENCE. REAL IMPACT.

U.S. DEPARTMENT OF ENERGY   Stanford University   SLAC NATIONAL ACCELERATOR LABORATORY

Disruption in the energy industry

Industry dynamics

- Technology-driven change → new business models
- Competitive forces → threats and opportunities
- Changing customer expectations → high-tech personalized digital experience

Reference: Deloitte, *2019 Power and Utilities Industry Outlook*

Power industry trends

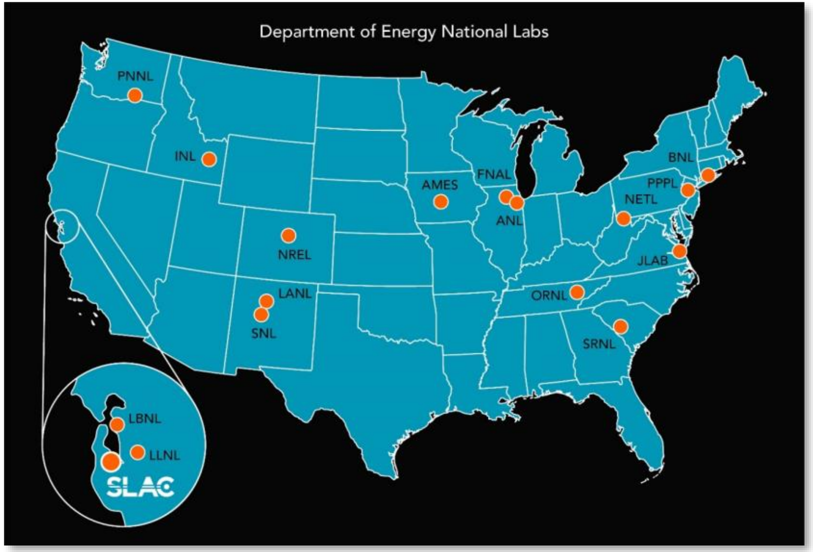
- Global energy demand plateaus after 2035 despite population expansion and economic growth
- Electricity consumption doubles until 2050 driven by electrification across key end uses
- Renewables will make up over 50% of generation by 2035; wind and solar already account for more than half of net capacity additions
- Oil demand peaks in the early 2030s; gas continues to grow its share of demand until it plateaus after 2035

Reference: McKinsey, *Global Energy Perspective 2019*

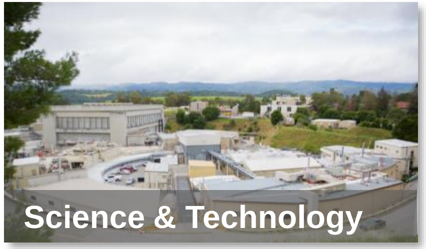
Opportunities

- Artificial intelligence
- Simulation, optimization, and control; dealing with complexity and uncertainty
- Cyber-physical security, blockchain
- New energy markets and business models
- Human and societal aspects, customer experience, human-in-the-loop

The U.S. Department of Energy national laboratory system is unique in the world in scale and impact



DOE Mission Areas

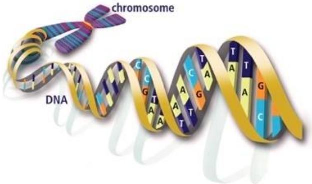


Annual Budgets

- Department of Energy: **$35.5B**
- DOE Office of Science: **$6.5B**
- DOE EERE: **$2.4B**

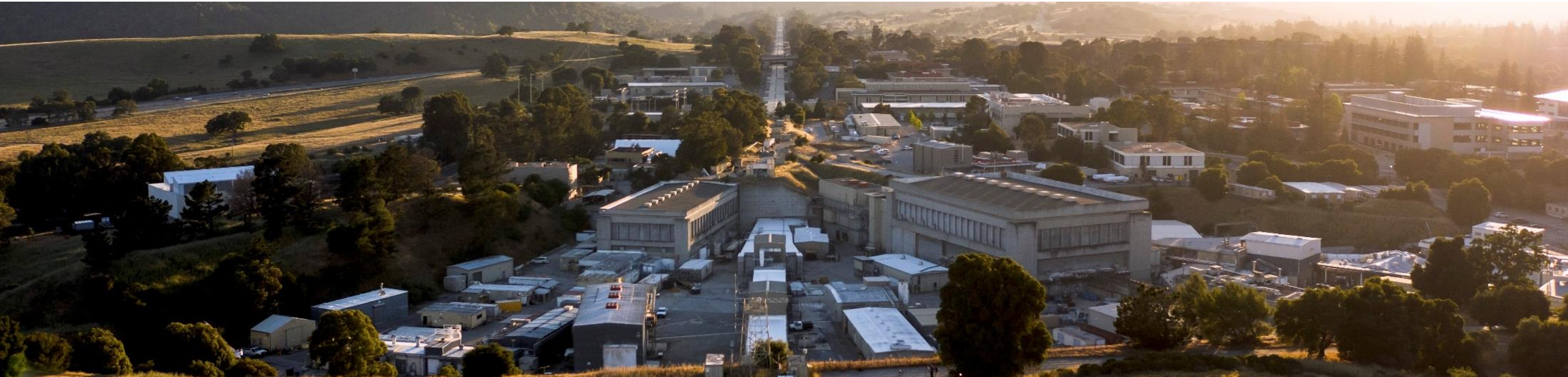
Beyond DOE Mission

- Human health, industry



SLAC National Accelerator Laboratory

- SLAC is a DOE national lab managed by Stanford University.
- SLAC is a vibrant multi-program laboratory solving real-world problems and advancing national interests.
- SLAC's mission is to explore how the universe works at the biggest, smallest, and fastest scales and invent powerful tools used by scientists around the globe. Our research helps solve real-world problems and advances the interests of the nation.
- SLAC has 1600 employees and an annual budget of $600 million.



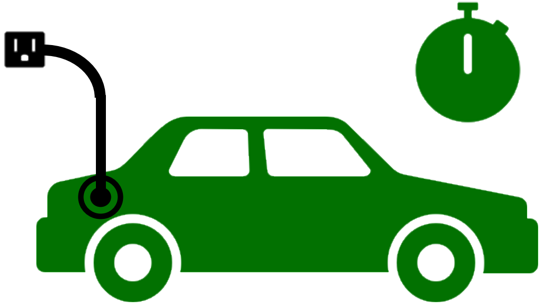
Three examples

- Batteries
- Materials
- Electric grid

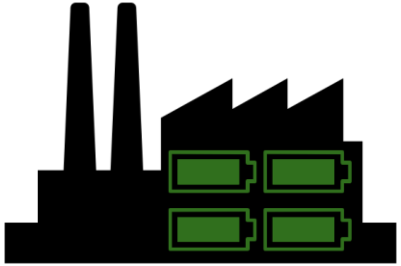
Data and model-driven prediction & optimization, William Chueh

For a given cell chemistry & design

Fast charging



Formation cycling



State-of-health indicators

Others:

R&D pipeline

Quality assurance

Safety prediction

(10 values/parameter)^ (5 parameters)
x (10 cells x 1000 cycles/cell)
= 1 billion battery-cycles!

Common challenge: large, hyper-dimensional design space

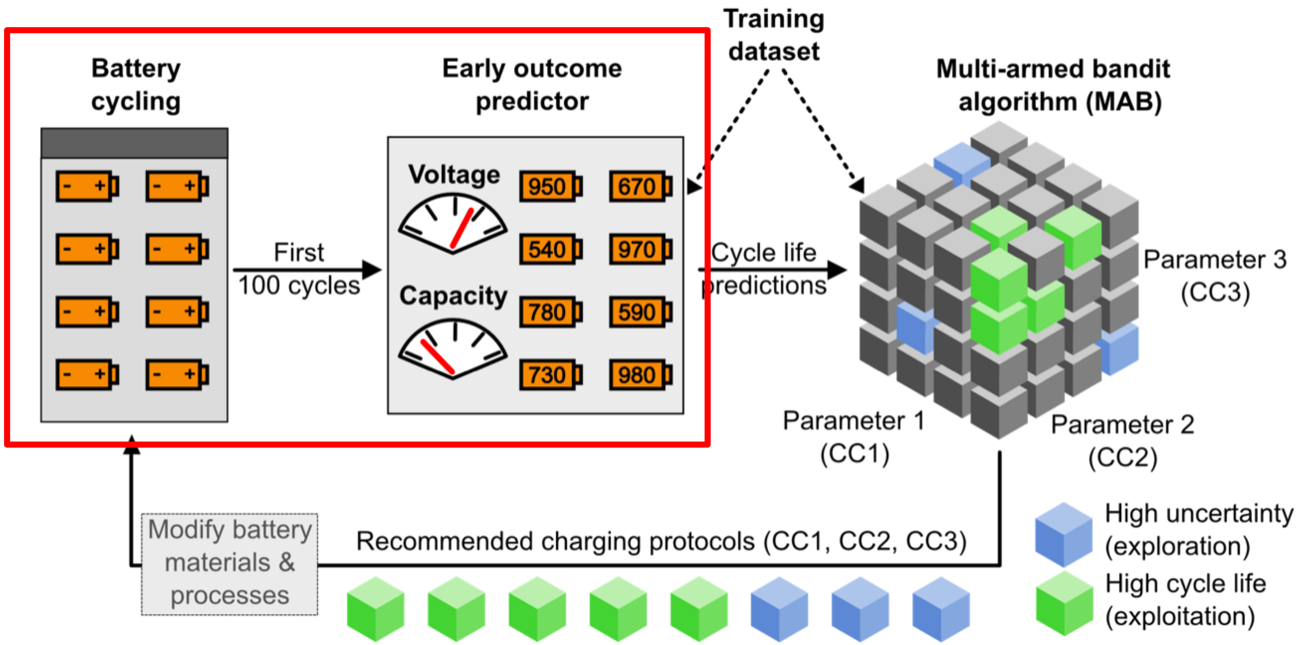
long assessment and optimization time

Data and model-driven prediction & optimization: For variable cell chemistry & design

- Optimizing electrode chemistry
- Optimizing synthesis
- Cell design
- Optimizing manufacturing

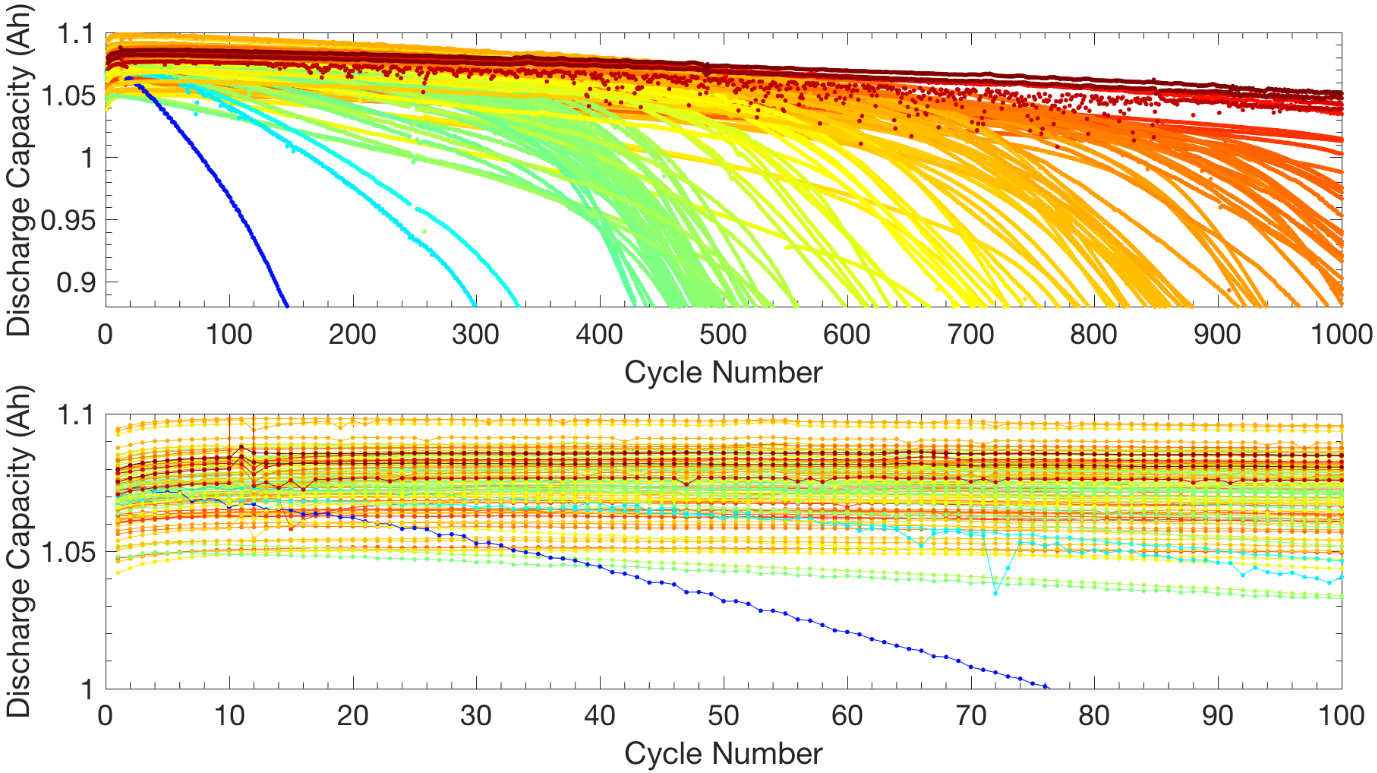
Common challenge: large, hyper-dimensional design space
long assessment and optimization time

Close-loop optimization & learning with early prediction



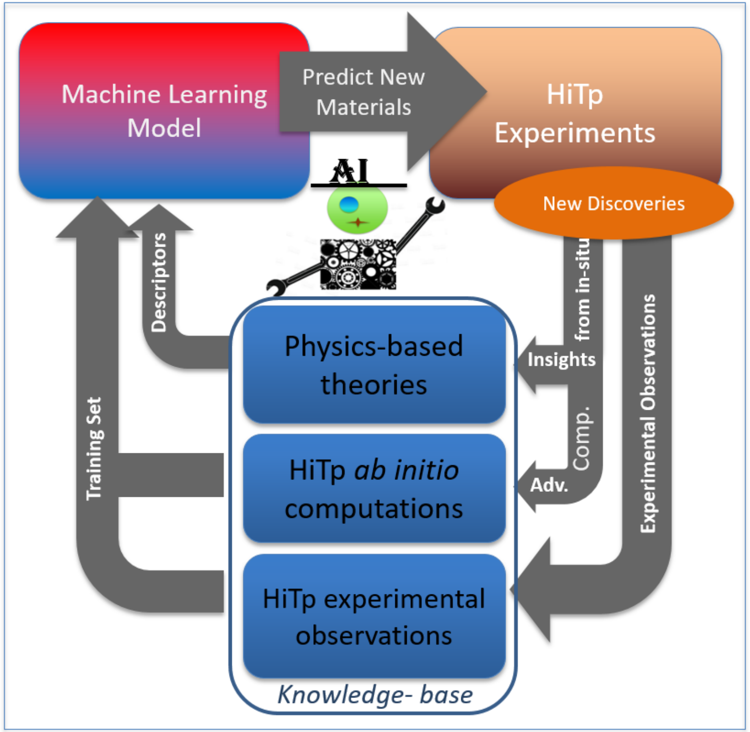
Grover, Markov, Attia, Jin, Ermon, Chueh. *Proc. AISTATS* (2018)
Severson, Attia, Chueh, Braatz *et al*. Nature Energy (2019)
Attia, Jin, Grover, Markov, Perkins, Ermon, Chueh, *et al*. In Preparation.

Predicting lifetime using early cycle capacities



Severson, Attia, Chueh, Braatz *et al*. Nature Energy (2019)

Accelerating Discovery of New Materials, Apurva Mehta



Energy Problems at heart are **Materials Problems**

We urgently need new

- Battery electrodes
- CO2RR (CO_2 reduction reaction) catalysts
- Heat-to-electricity (thermoelectric) converters
- Corrosion and wear-resistant coatings
- Lightweight and strong structural materials

Currently it takes **over 20 years** to develop a new material!

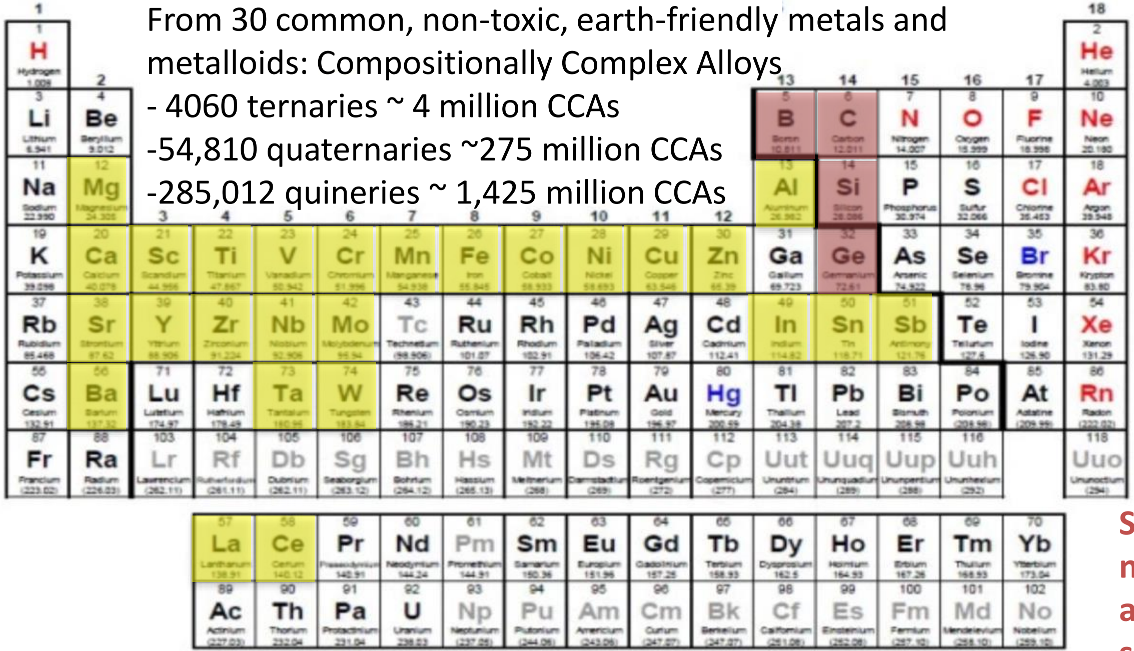
- Can we find them faster and do it cheaper?

At SLAC we take **multiple sources of knowledge** (theory, computations, and experiments) and **combine them with machine-learning** to **accelerate discovery of new materials**.

Millions/Billions of Undiscovered Materials

Promise of Materials Genome Initiative

From 30 common, non-toxic, earth-friendly metals and metalloids: Compositionally Complex Alloys
- 4060 ternaries ~ 4 million CCAs
-54,810 quaternaries ~275 million CCAs
-285,012 quineries ~ 1,425 million CCAs

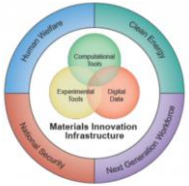


Make+Measure
10 CCAs/day
→ 1000 yr to
search all
ternaries

Make+Measure
1 ternary/day
→ 10 yr to
search all
ternaries

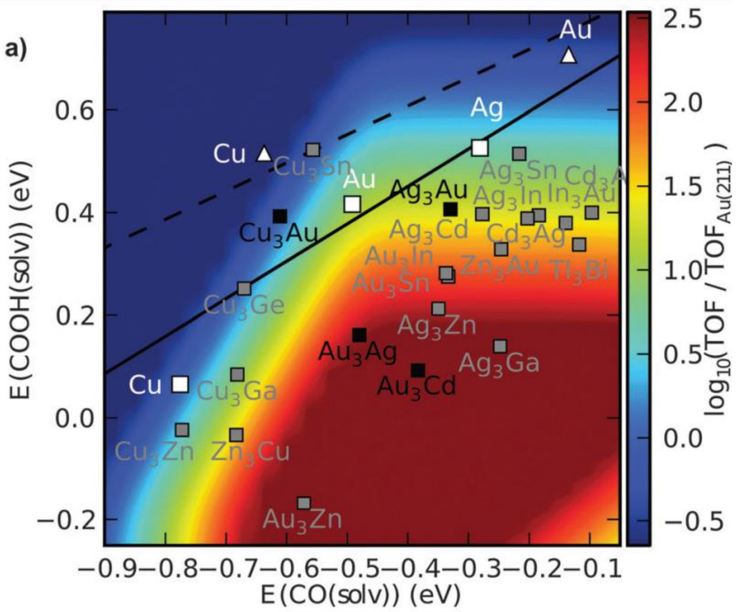
Still too long, need guidance to accelerate the search futher

- Can Computation Provide Guidance?,
  - But what if the theories are not accurate?



Going Beyond Simple Materials: Two Examples

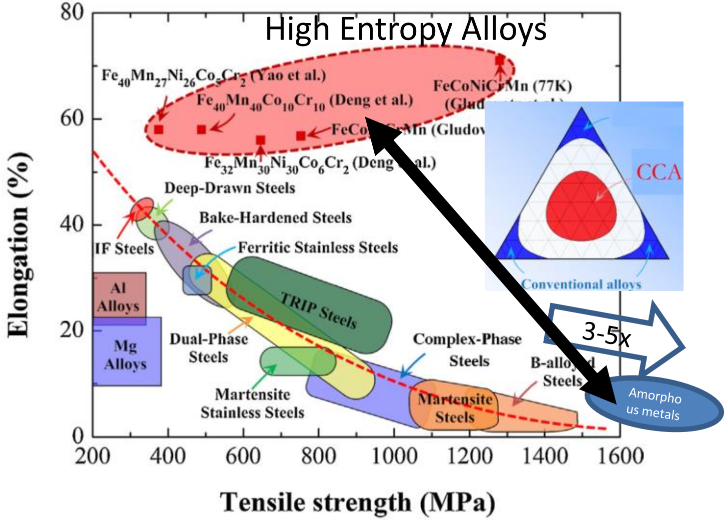
- CO_2 Reduction to Fuels



- Electro-catalytic Reduction

H. A. Hansen, C. Shi, A. C. Lausche, A. A. Peterson and J. K. Nørskov; Phys. Chem. Chem. Phys., 2016, 18, 9194--9201 | 9197

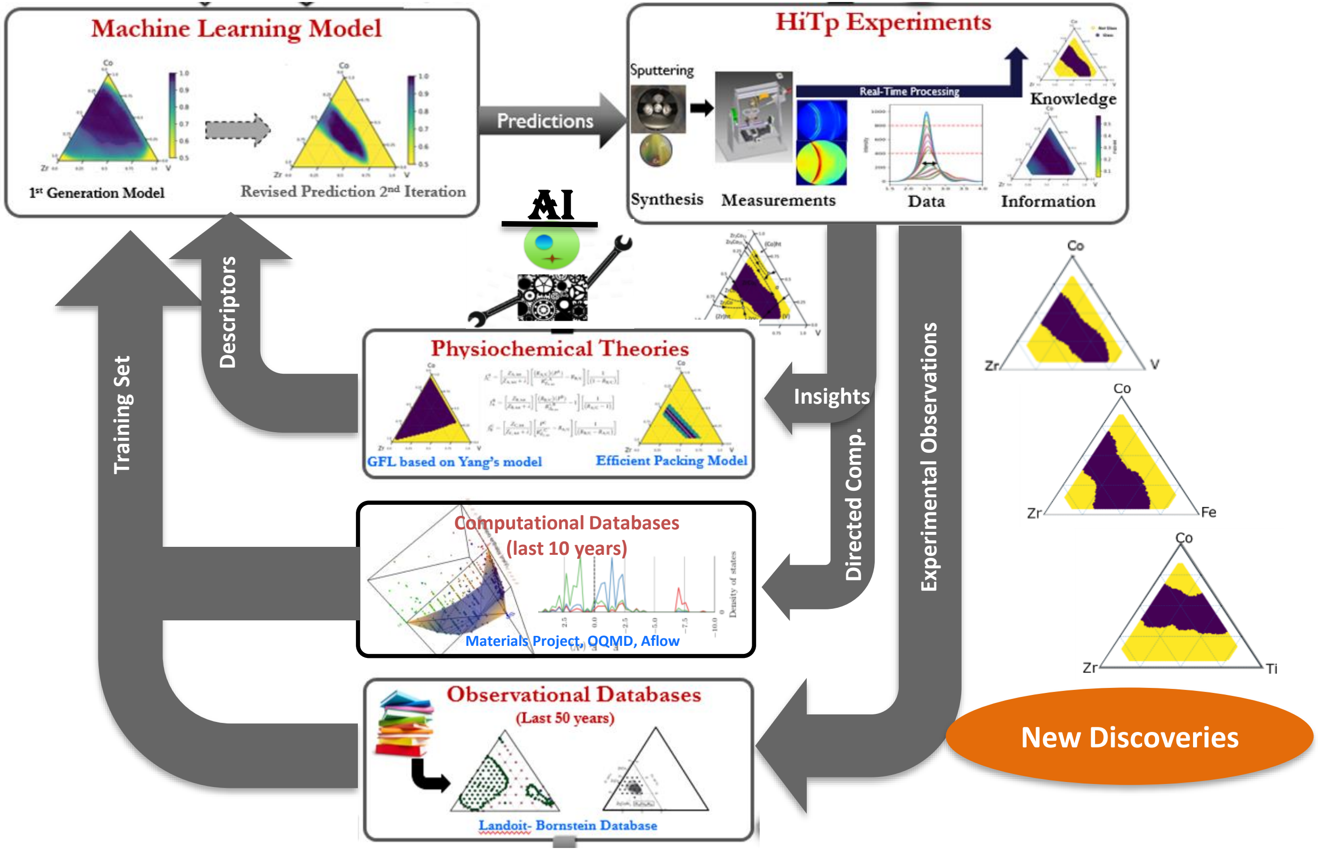
- Structural Alloys



- Compositionally Complex Alloys

Y.F. Ye, Q. Wang, J. Lu, C.T. Liu and Y. Yang; Materials Today, 19, 349, 2016

AI + HiTp Experiments Accelerates Discoveries

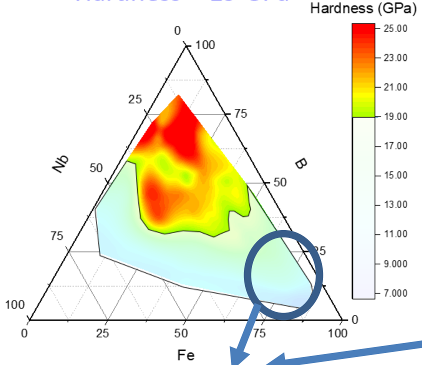


New Metallic Hard & Wear-resistant Coatings

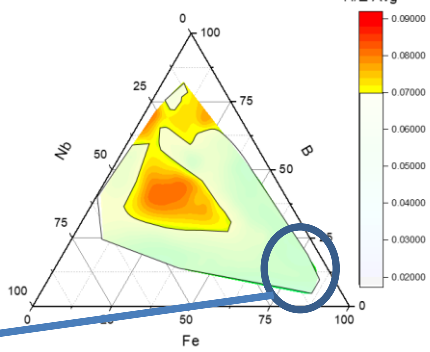
SLAC

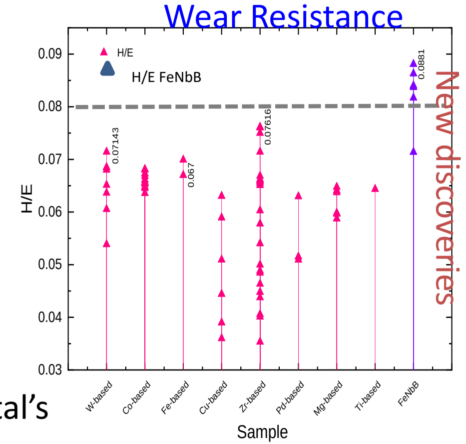
Amorphous Complex Alloys

Hardness > 19 GPa



Wear Resistance > 0.07



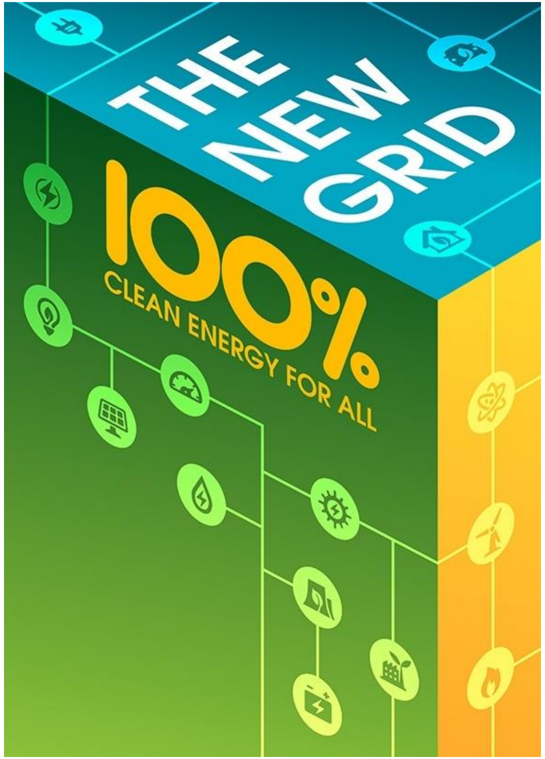


Region extensively studied and base composition for Liquidmetal's commercial product. (New Discoveries > 4x harder.)

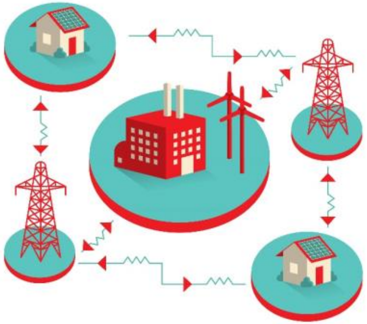
Material	Hardness GPa	Wear-Resistance (H/E)
Hardened SS 404	7.3	~0.01
Nitrides (CrN, ZrN, TiN, TiAlN)	22 – 35	0.04 – 0.09
FeNbB – SAS (New Discovery)	9 – 29	0.05 – 0.09

If Scaled to Bulk, the New Alloys Promise to be more than 3x Stronger than Steel but Half the Weight

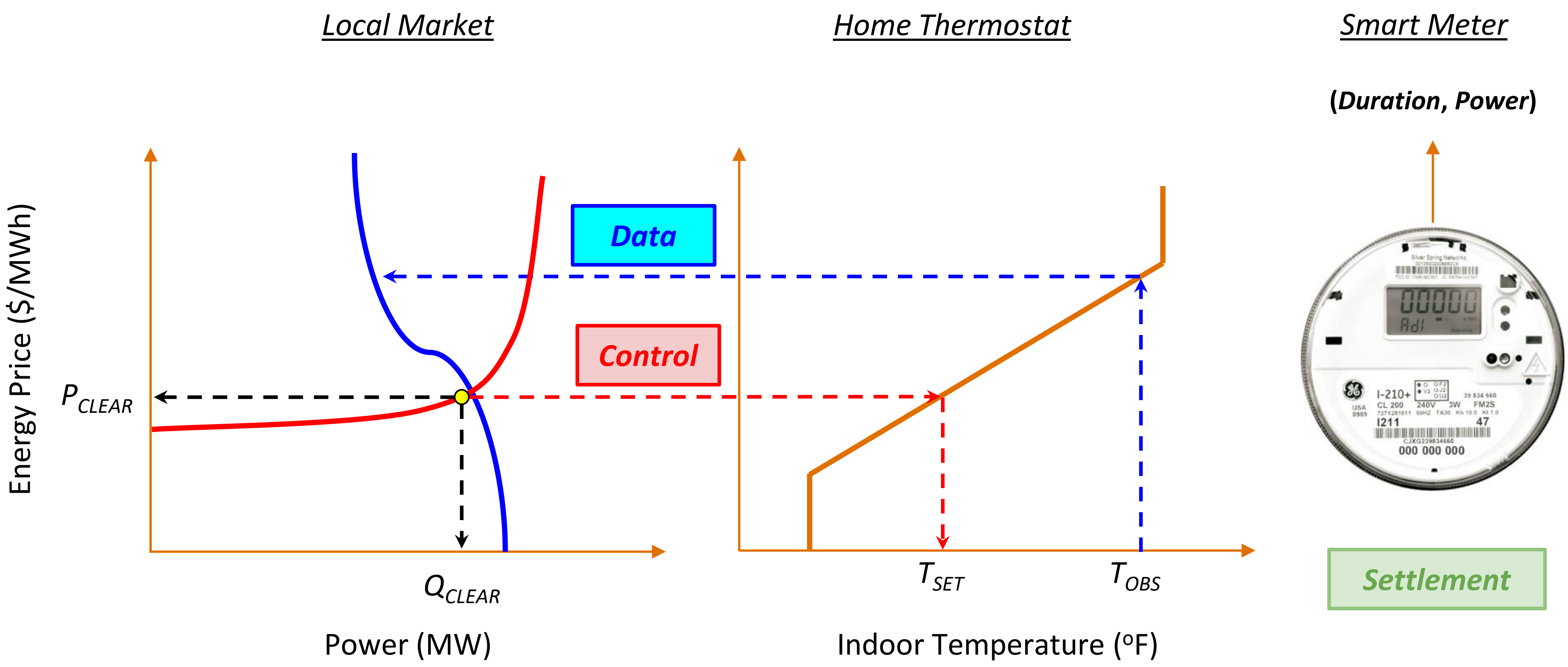
Converting Today's Electrical Power Grid to Support 21st Century Energy Needs, David Chassin & Mayank Malik



- SLAC's **Grid Integration, Systems and Mobility group** (GISMo) is part of the SLAC's Applied Energy Division
- New tools are being developed at SLAC and Stanford for **modeling and optimizing the grid**
- **Massive data collection/analytics** and **machine learning** projects support the integration of distributed energy resources
- **Transactive control** uses market mechanisms to match supply and demand
- **Blockchain** enables security and functionality



Transactive systems use prices as control signals



TC enables the three price signals that matter

Energy Storage

$\$/MW.h^2$

Examples:

- Batteries
- Pumped storage
- Thermal storage

System Capacity

$/MW.h

Examples:

- Generators
- Power lines
- Transformers

Most energy markets only use $/MWh, which is collapsing due to large amounts of new renewables with zero marginal energy costs.

Resource Ramping

$/MW

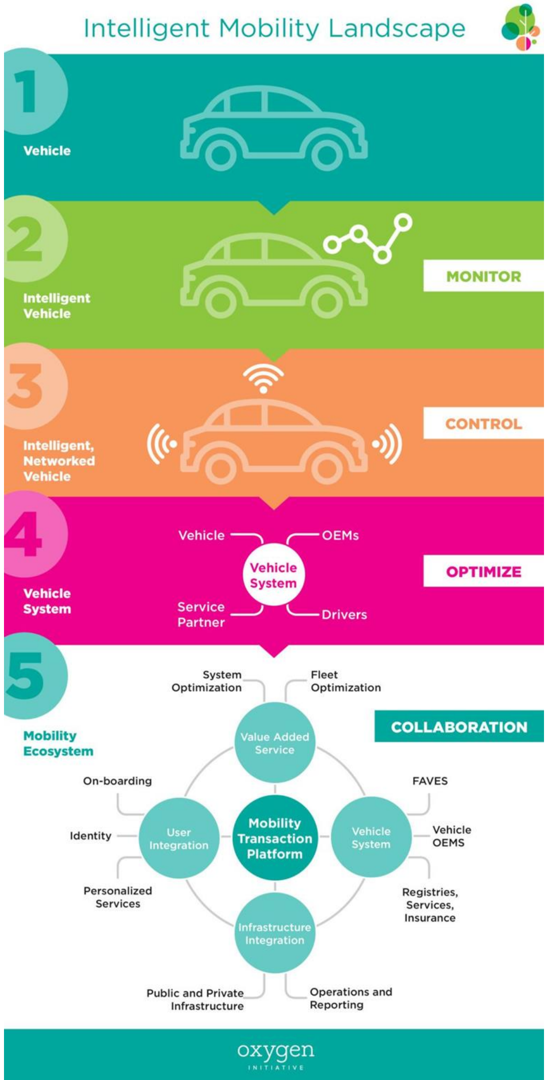
Examples:

- Thermostats
- Vehicle chargers
- Appliances

Blockchain in the Energy Industry

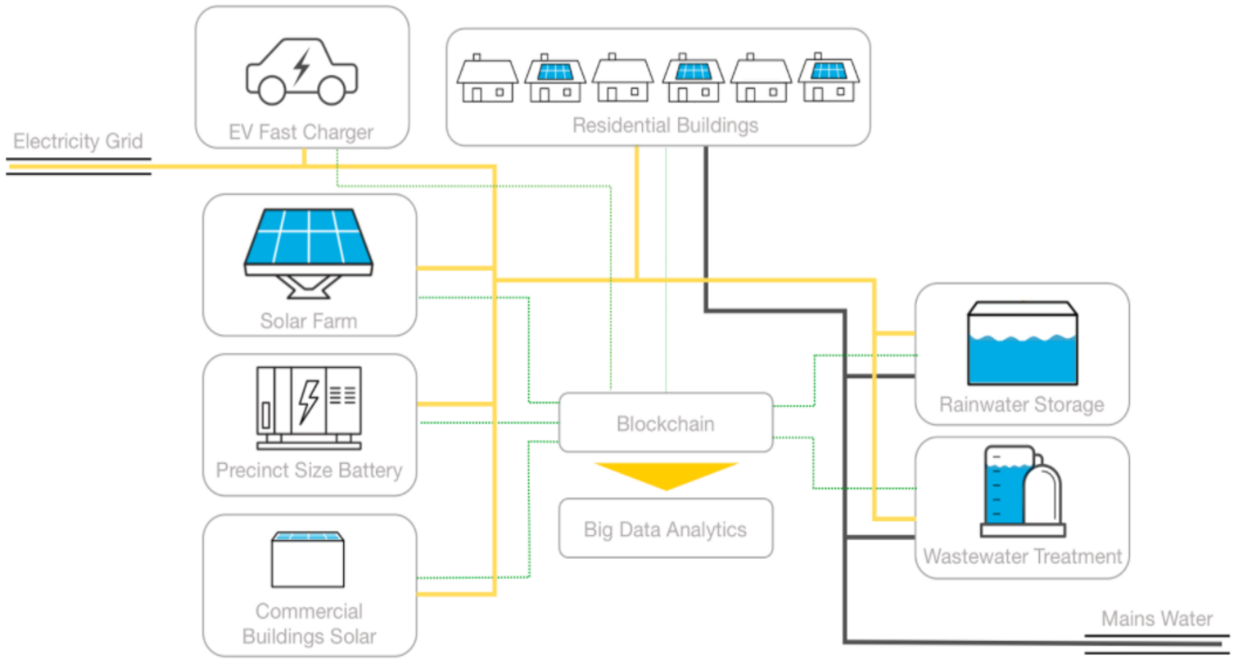
Vehicle-2-Grid: Oxygen Initiative

V2G uses electric vehicles as an energy storage solution while they are parked, which is on average more than 80% of the time. This process allows EV owners to make money by selling electricity back to the grid.



Systems Integration: Power Ledger

Provides a peer-to-peer trading platform for micro-grids, for people to sell their own excess energy from their renewable energy sources on a market place that provides energy buyers with cheaper renewable energy.



Power Ledger 2017 press release

The future

Technology-enabled solutions for energy systems that are

- Efficient
- Sustainable
- Flexible
- Affordable
- Reliable
- Safe

Opportunities for energy incumbents, large companies in adjacent industries, and start-ups.