NATIONAL NETWORK FOR CRITICAL TECHNOLOGY ASSESSMENT

SECURING AMERICA'S FUTURE

A Framework for Critical Technology Assessment

Chips & Science Act Legislates National Technology Strategy

August 9, 2022

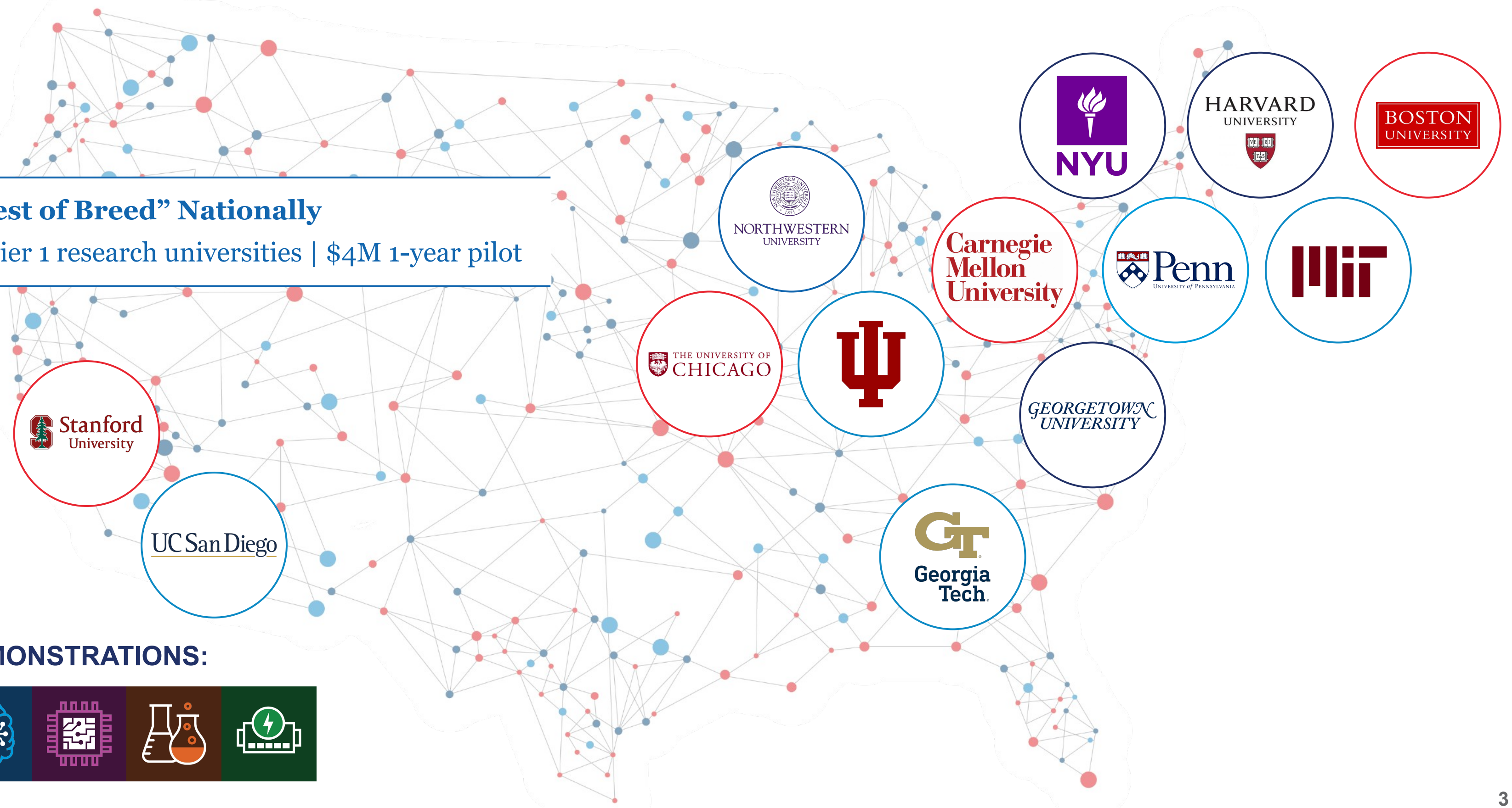
"In consultation with the interagency working group… [the National Science Foundation Technology Innovation and Partnerships Directorate will] identify and annually review and update a list of

1. Not more than 5 United States societal, national, and geostrategic challenges that may be addressed by technology
2. Not more than 10 key technology focus areas … *and*
3. Evaluate the relationship between U.S. societal, national, and geostrategic challenges and the key technology focus areas."

A National Network for Critical Technology Assessment

“Best of Breed” Nationally

13 tier 1 research universities | $4M 1-year pilot



5 AREA DEMONSTRATIONS:

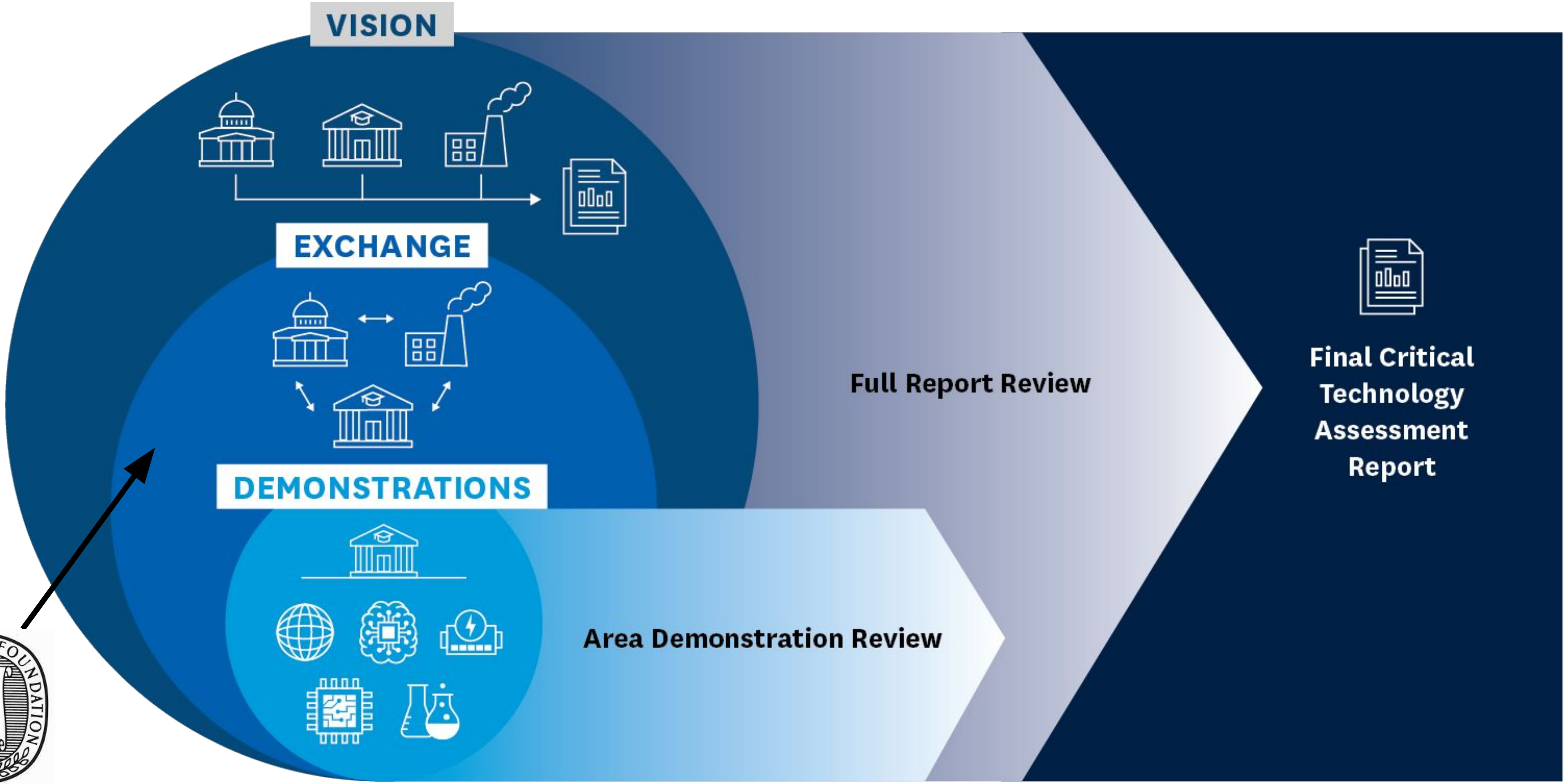
Pilot Year Goals and Evaluation

VISION FOR NATIONAL CRITICAL TECHNOLOGY ASSESSMENT

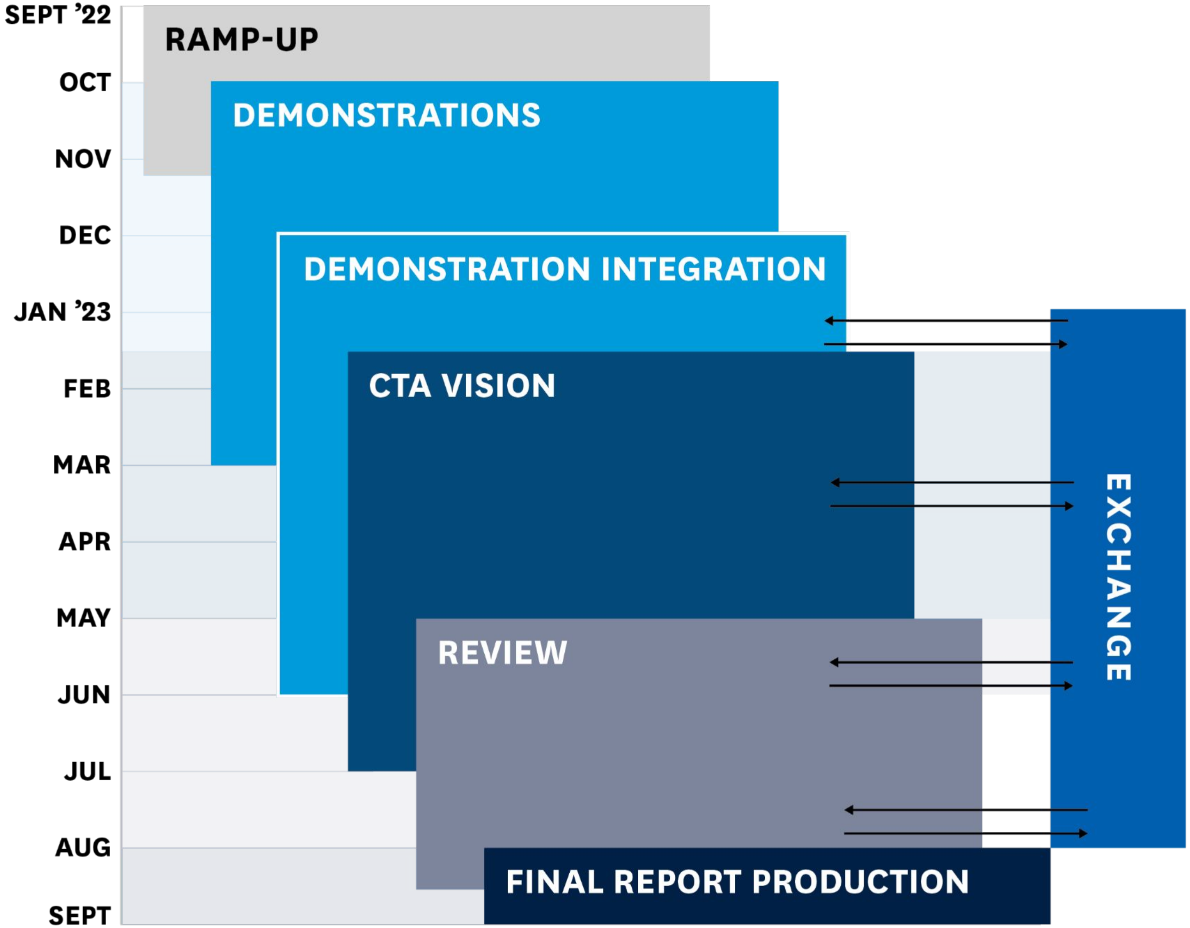
including current capabilities, gaps, and national investment and organizational form needed to realize that vision

- Demonstrate *how analytics can help quantify* the value of different science and technology investments for the US's security, economic, and social goals
- Demonstrate *potential advantages of a network* over other organizational forms

Pilot Year Concentric Activities Build to the Final Report



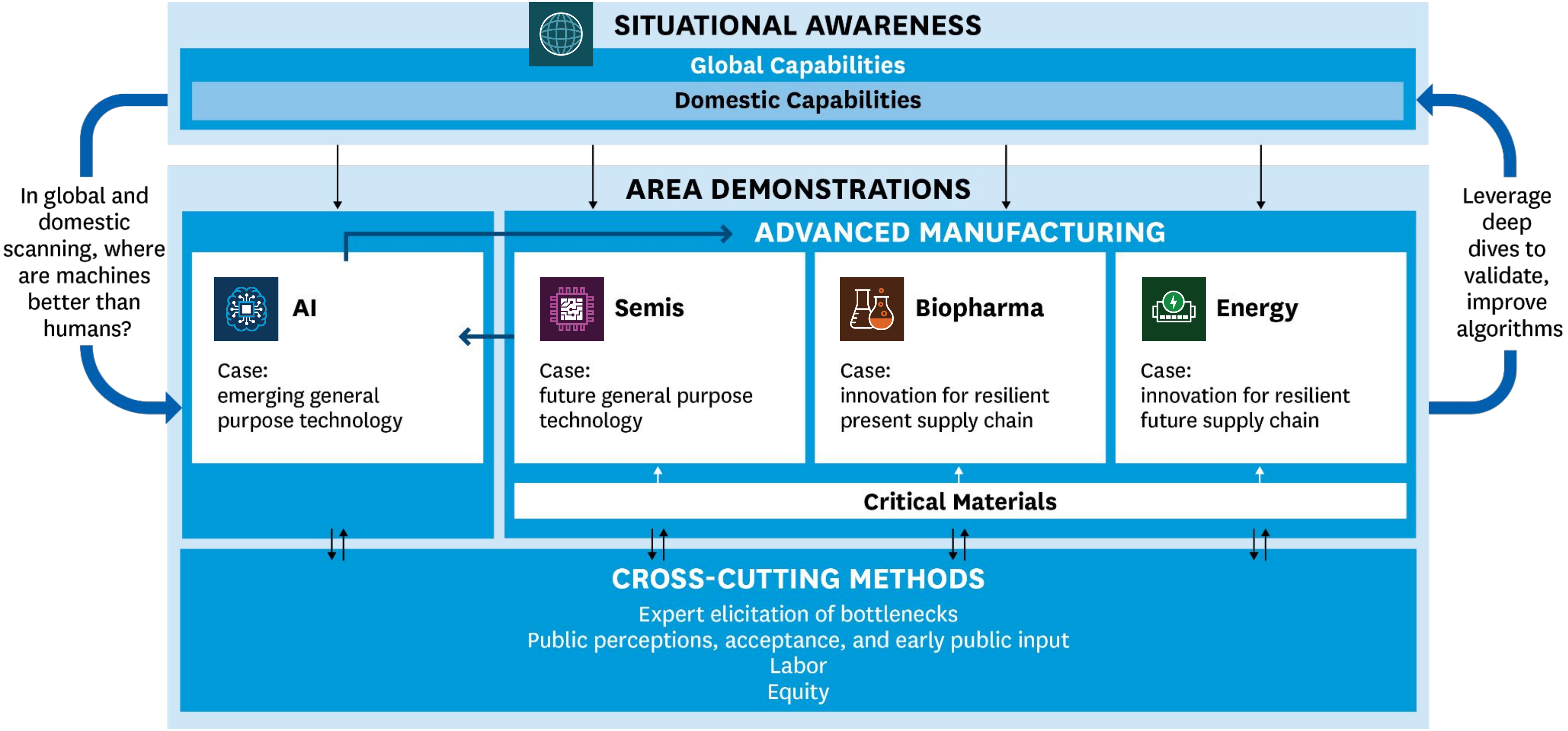
One-Year Timeline



WORKSHOP:

- AI
- Biopharma
- Semiconductors
- US leaders
- Global Compet.
- Labor & equity

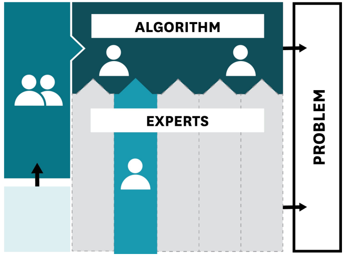
Demonstration Selection



Multidisciplinary Lenses: Dimensions of Integration

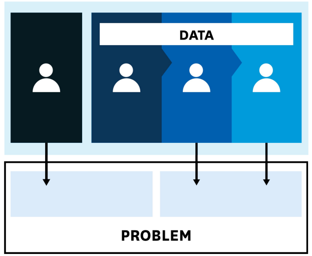
GLOBAL COMPETITIVENESS

Algorithm scanning informed by expert knowledge



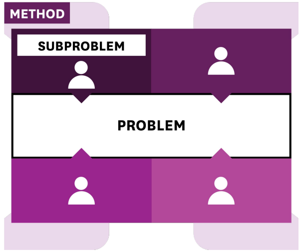
AI

Different data complement and point in *same direction*



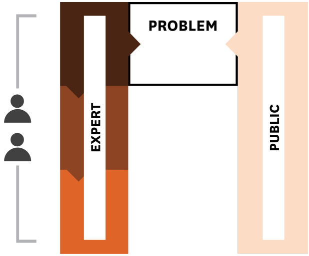
SEMIS

Different disciplines, methods solve *different* subproblems



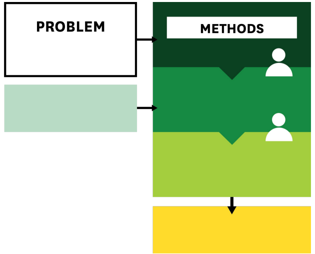
BIOPHARMA

Different disciplines, methods offer *different perspectives*

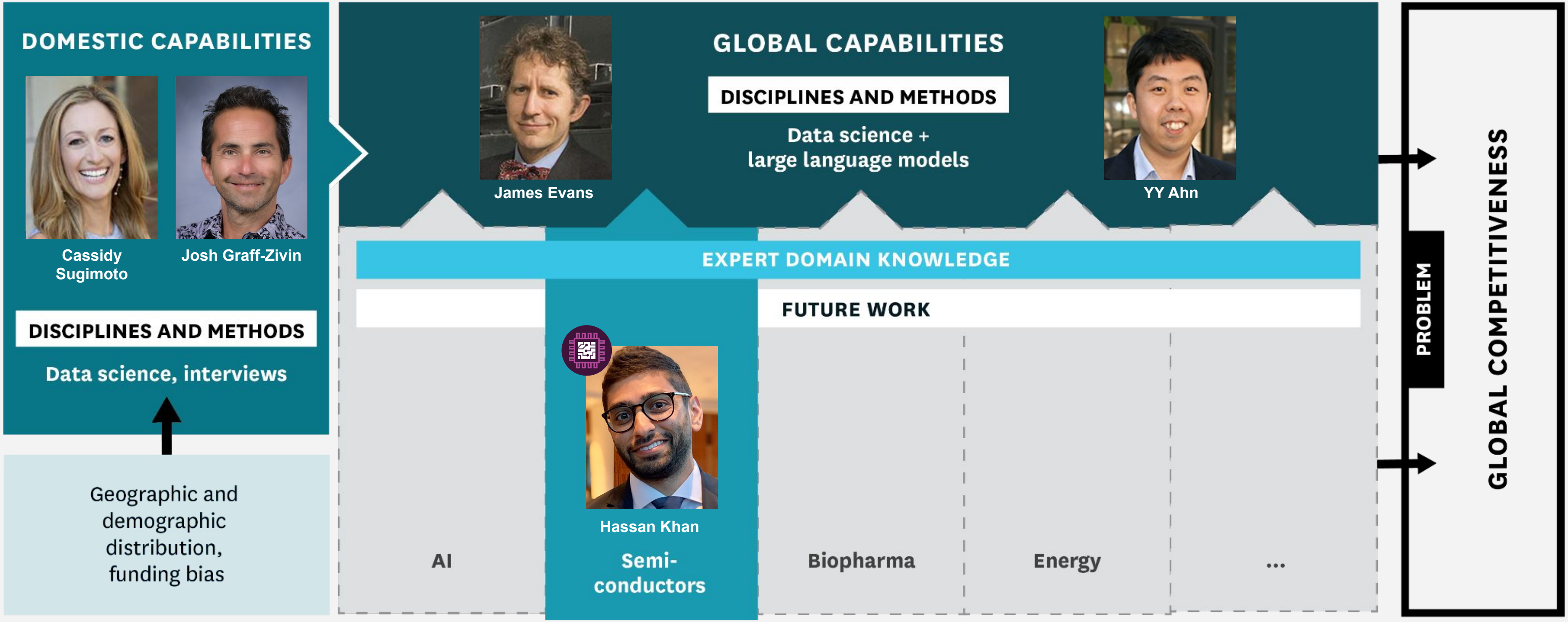


ENERGY & CRITICAL MATERIALS

Combined disciplines, methods produce new results



GLOBAL COMPETITIVENESS DEMONSTRATION



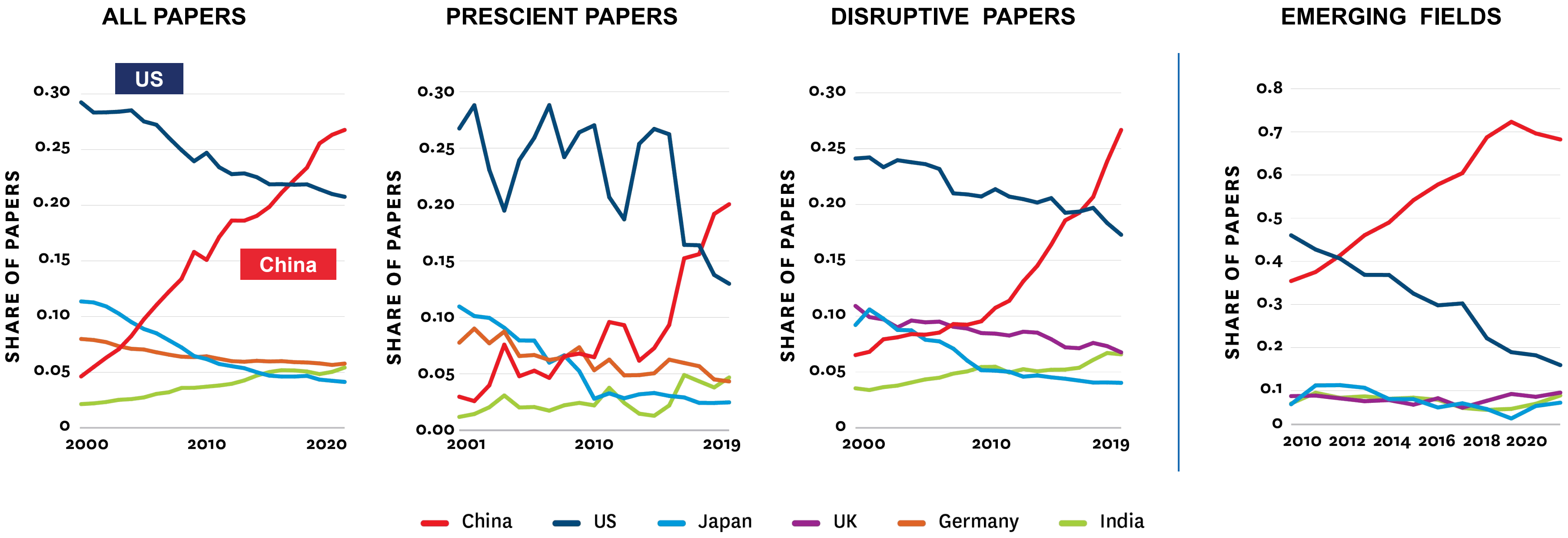
MOTIVATION

The US currently lacks sophisticated and systematic mechanisms to assess its global competitiveness in science and technology relative to other countries

Prior to this year, general understanding has been that even if China had surpassed the United States in the *total number* of scientific publications, the United States was more creative and disruptive

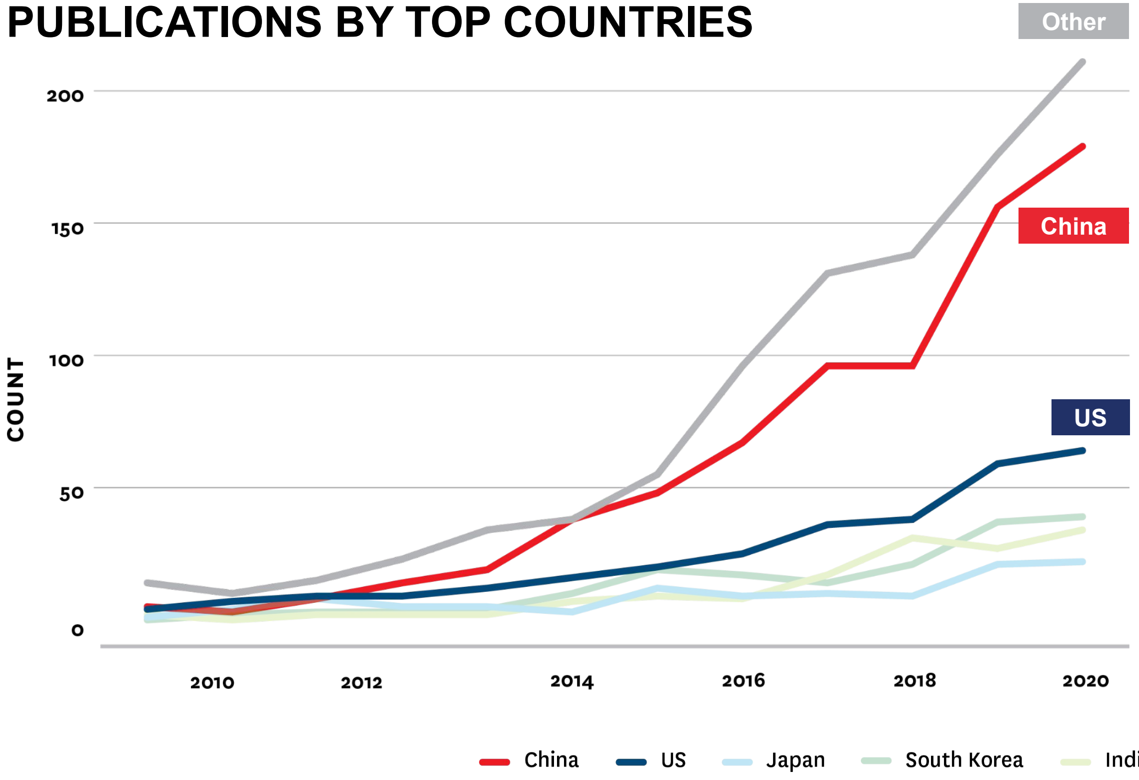
China has the highest share globally of scientific papers that…

- cause existing research to pivot in new directions (prescient)
- initiate new lines of research (disruptive)
- lead to the emergence of new fields



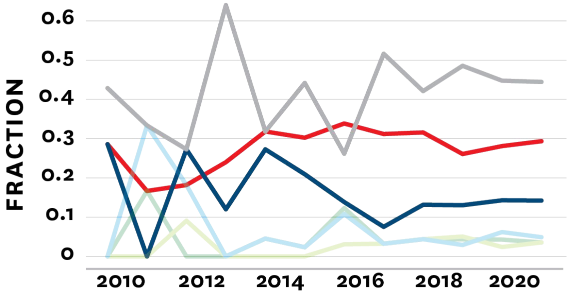
Example - Future of Computing

NUMBER OF ALL POST-CMOS-RELATED PUBLICATIONS BY TOP COUNTRIES

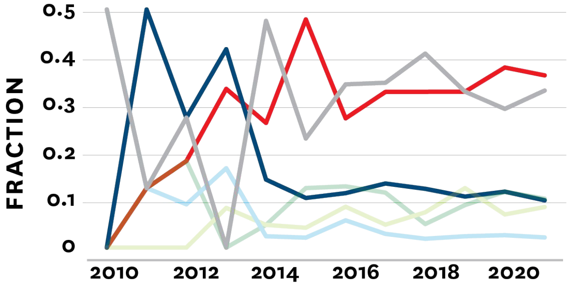


DISRUPTIVE PAPERS

Topological insulators

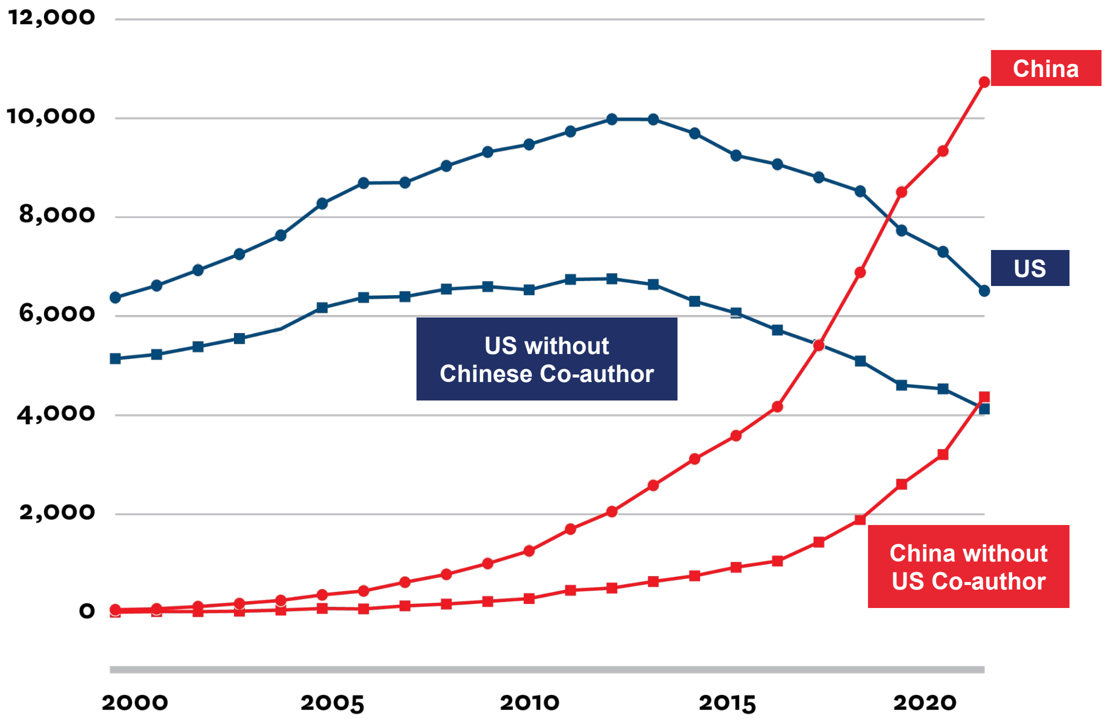


2D material channel FETs



Chinese and US researchers also collaborate more on scientific publications than any other two nations

Causal analysis:
both countries would **substantially reduce** their production of scientific knowledge if collaborations were cut off.



Aghion et al., 2023. "Does Chinese Research Hinge on US Coauthors? Evidence from the China Initiative." *NBER Working paper.*

RECOMMENDATIONS

These initial models and measures require further exploration with experts at field- and paper-specific levels, but the findings raise concerns that deserve much greater attention.

The US needs a sophisticated and systematic mechanism to assess its global competitiveness in science and technology relative to other countries

- AI and Large language models (LLMs) are revolutionizing the competitiveness assessments possible
- These models are need to be complemented with expert knowledge… but on-the-ground open intelligence programs have been discontinued or downsized

The US may need a better system for cultivating and balancing a research portfolio that funds innovative, higher-risk approaches

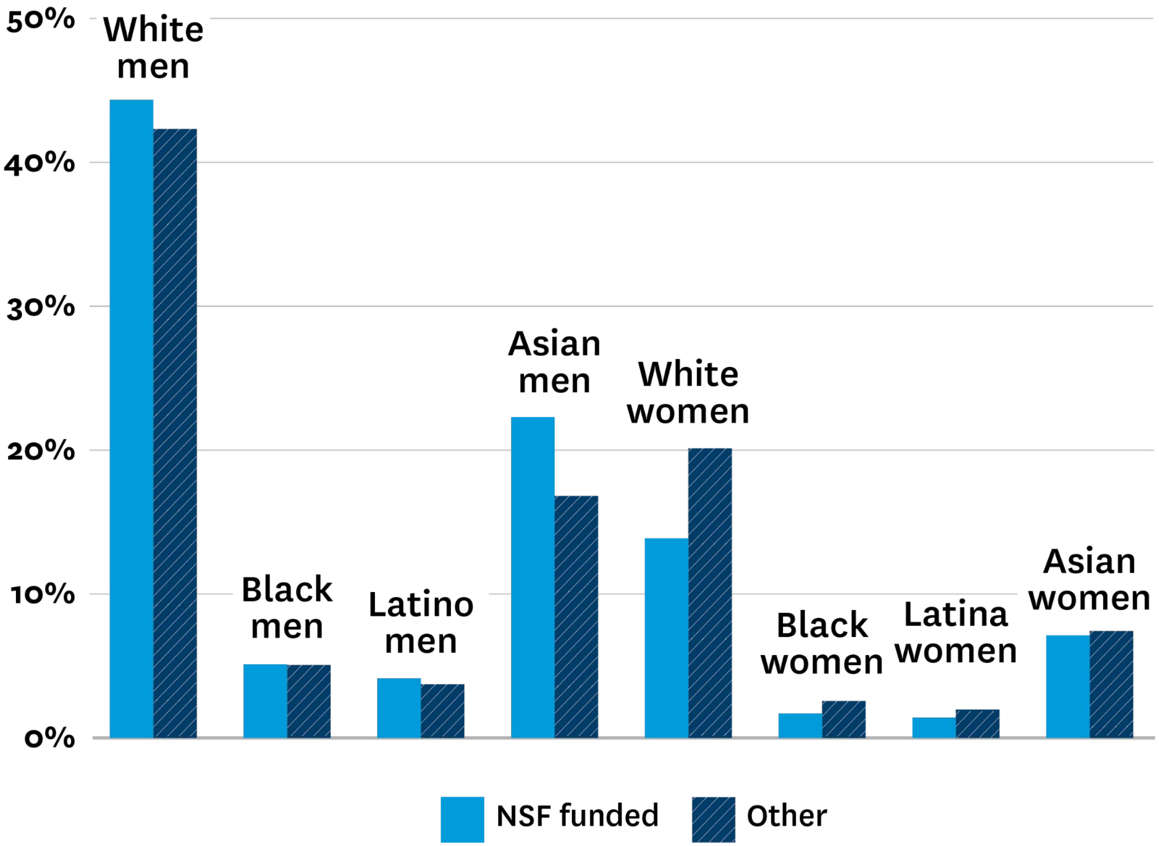
RECOMMENDATIONS

This systemized approach should also be applied domestically to inform legislators and agencies of regional capabilities that could support US competitiveness and ways to advance them.

NSF funding of science is failing to engage the full talent base

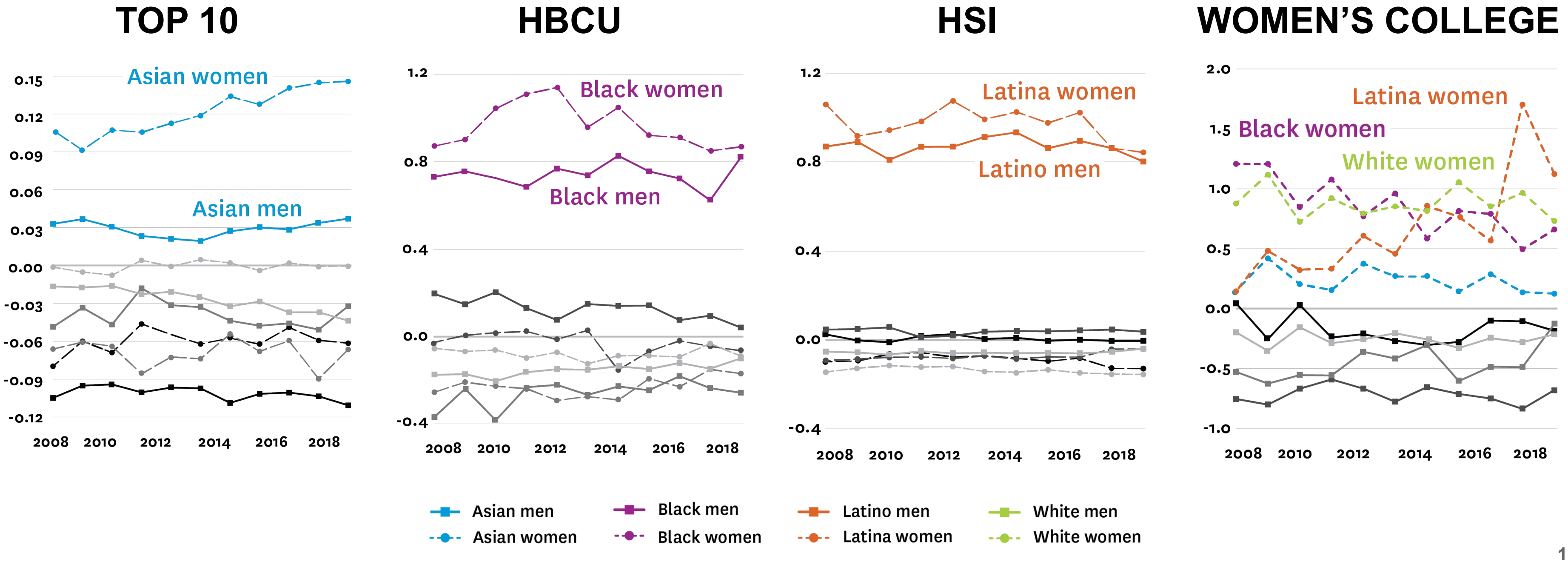
Compared to all funded US publications, the NSF disproportionately funds research by men over women authors. The ratio has remained relatively stable over time.

In certain critical fields (such as computing): NSF is failing to fund the women and scientists of color with the highest impact in their fields.



Funding disparities have strategic implications for innovation.

- Innovation is enhanced by engagement of geographically and demographically diverse researchers and collaborations of diverse teams
- Disparities are exacerbated by the concentration of funding in elite institutions



RECOMMENDATIONS

The US is failing to engage the full capabilities of the Nation’s workforce

Systemic and organizational change will be necessary to change these dynamics

The NSF should:

- Explore how real-time tools combined with best practices from decision sciences may help overcome biases in the federal review process.
- Partner with other S&T organizations to create comprehensive and equitable datasets.
- Design experiments to assess:
  - which interventions and policies are most effective in increasing participation of women and minoritized groups in science.
  - how the institutional portfolio for funding and deconcentration of funding across institutions may change the direction and rate of scientific outcomes.

AI DEMONSTRATION

DATA

Dashun Wang

Publications, Syllabi

DATA

Erik Brynjolfsson

American Community Survey of Employment, Job postings

Erik Brynjolfsson

US Census Bureau Survey on AI Adoption, Job Postings

Lee Branstetter

Patent data, US Census firm data

Dewey Murdick

Thema Monroe-White

OPPORTUNITIES FOR AI TO ACCELERATE SCIENTIFIC DISCOVERY

SUBPROBLEM

IMPACT OF AI ON PRODUCTIVITY, JOBS

SUBPROBLEM

PROBLEM

MOTIVATION

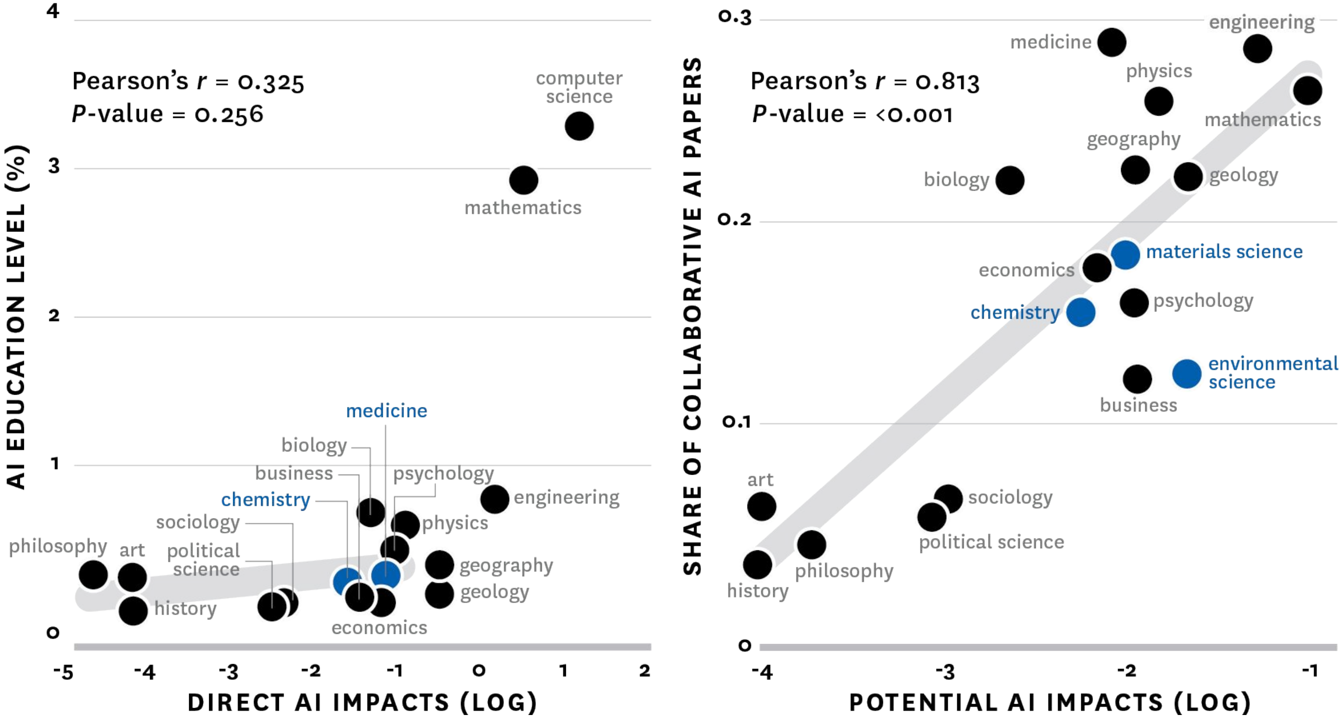
Academics, policymakers, industry experts, and the public have feared that artificial intelligence (AI) will lead to a loss of jobs, and productivity gains have proven difficult to measure.

Using novel data and measurement techniques, we demonstrate that AI has the potential to substantially increase scientific discovery, productivity, output, and employment across the US economy,

BUT, the invention/diffusion process is still in early stages and not all firms, regions, demographics, or scientific fields are benefiting.

AI can accelerate scientific discovery, but not all fields benefitting

We are underutilizing AI in disciplines where AI has the potential to have major scientific impacts

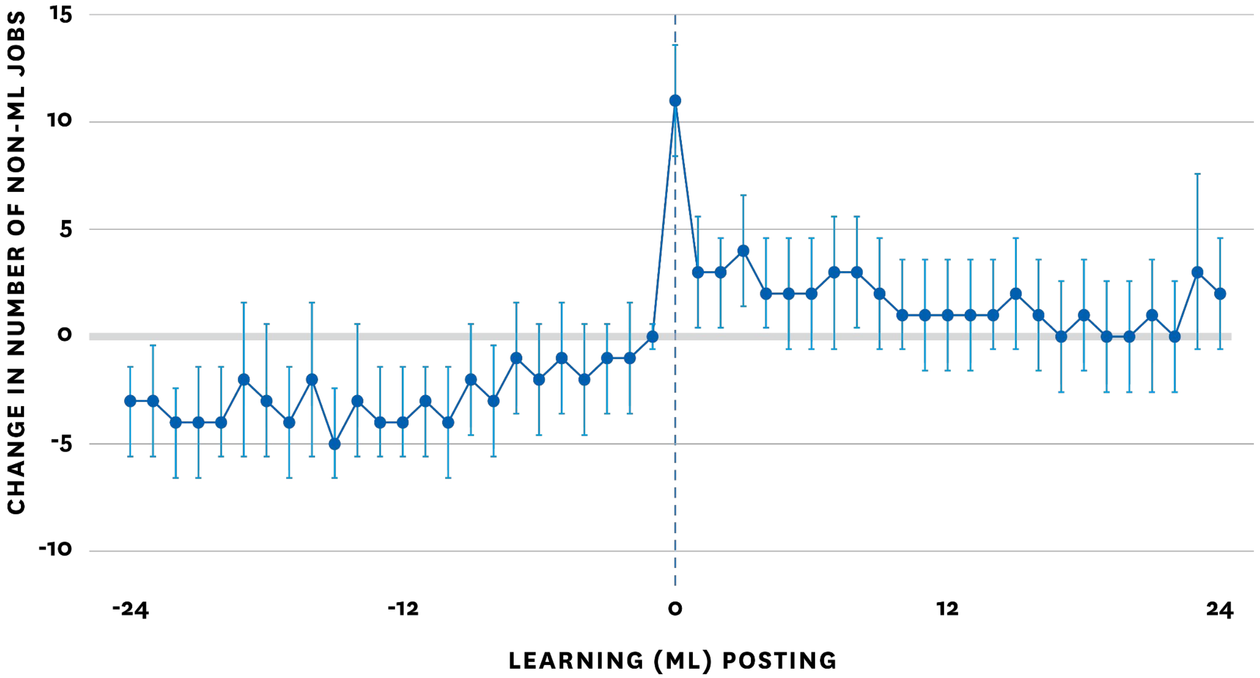


RECOMMENDATIONS

Policy can support scientific and technology disciplines in discovering (through collaboration) and training (through education) the best uses of AI in their fields

- Fund and facilitate cross-department collaborations between scientific and engineering disciplines and AI experts.
- Fund the development of university curriculum in the best uses of AI in their scientific and engineering fields.
- As shown by previous analyses, expand the AI-related professoriate immediately by:
    - (i) broadening opportunities for foreign graduates to remain in the United States
    - (ii) increasing funding and support programs that facilitate female and underrepresented groups in their graduate study in AI-related fields

AI Adoption Increases Jobs, Worker Productivity

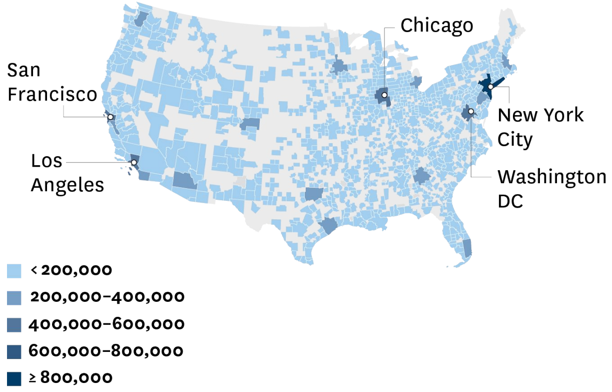


More AI job postings correlates with more non-AI job postings at firms

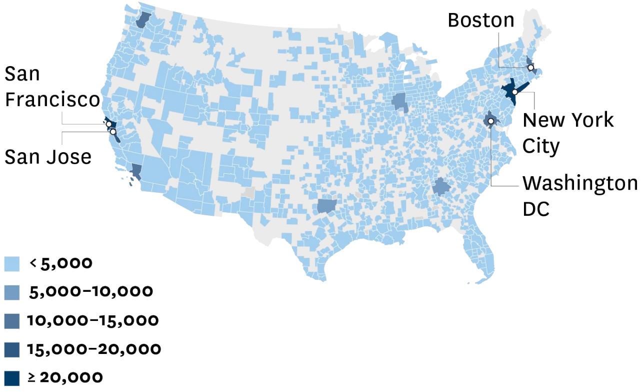
Source/Reference

Firms that are farther ahead in AI adoption are growing in revenue and employment, but those benefits are concentrated in large firms and limited geographic regions and demographics.

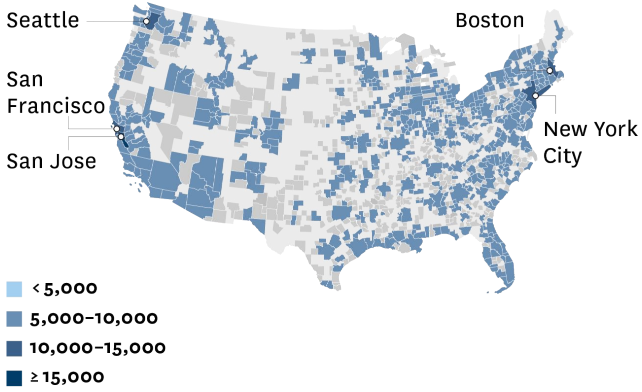
AI EMPLOYMENT IN 2019
(American Community Survey, CSET)



AI JOB POSTINGS IN 2019
(Lightcast, Stanford University)



AI PATENTS IN 2019
(USPTO, CMU)



Note: 357,188 AI employment records did not have location data.
Maps created by: Center for Security and Emerging Technology | Sources: American Community Survey, Lightcast, Stanford University NNCTA Team, USPTO, Carnegie Mellon University NNCTA Team

RECOMMENDATIONS

The United States needs to find ways to diffuse AI capabilities more broadly so that its benefits are more widespread.

To support smaller enterprises in adopting and benefiting from AI:

- Expand the ranks of AI workers with the skills needed to work at the disciplinary frontier

To enable more regions and demographics to benefit from AI:

- Authorize funding to staff AI office and workforce support initiatives *(e.g National AI Initiative Office for Education and Training)*
- Develop a federal framework of technical and nontechnical AI work roles & competencies
- Establish federal grant programs for AI industry-academia partnerships

SEMICONDUCTOR DEMONSTRATION

DISCIPLINES AND METHODS

Data science (with natural language processing)

SUBPROBLEM

US competitiveness: scientific knowledge & commercialization

YY Ahn

DISCIPLINES AND METHODS

Engineering + economics

SUBPROBLEM

Workforce capabilities, constraints

Christophe Combemale

PROBLEM

REGAINING US COMPETITIVENESS IN SEMICONDUCTORS

Hassan Khan

Potential value next gen semi devices

SUBPROBLEM

Economics (productivity measurement)

DISCIPLINES AND METHODS

Neil Thompson

Technical bottlenecks and costs to commercializing next gen semiconductor devices

SUBPROBLEM

Engineering: Expert elicitation

DISCIPLINES AND METHODS

Granger Morgan

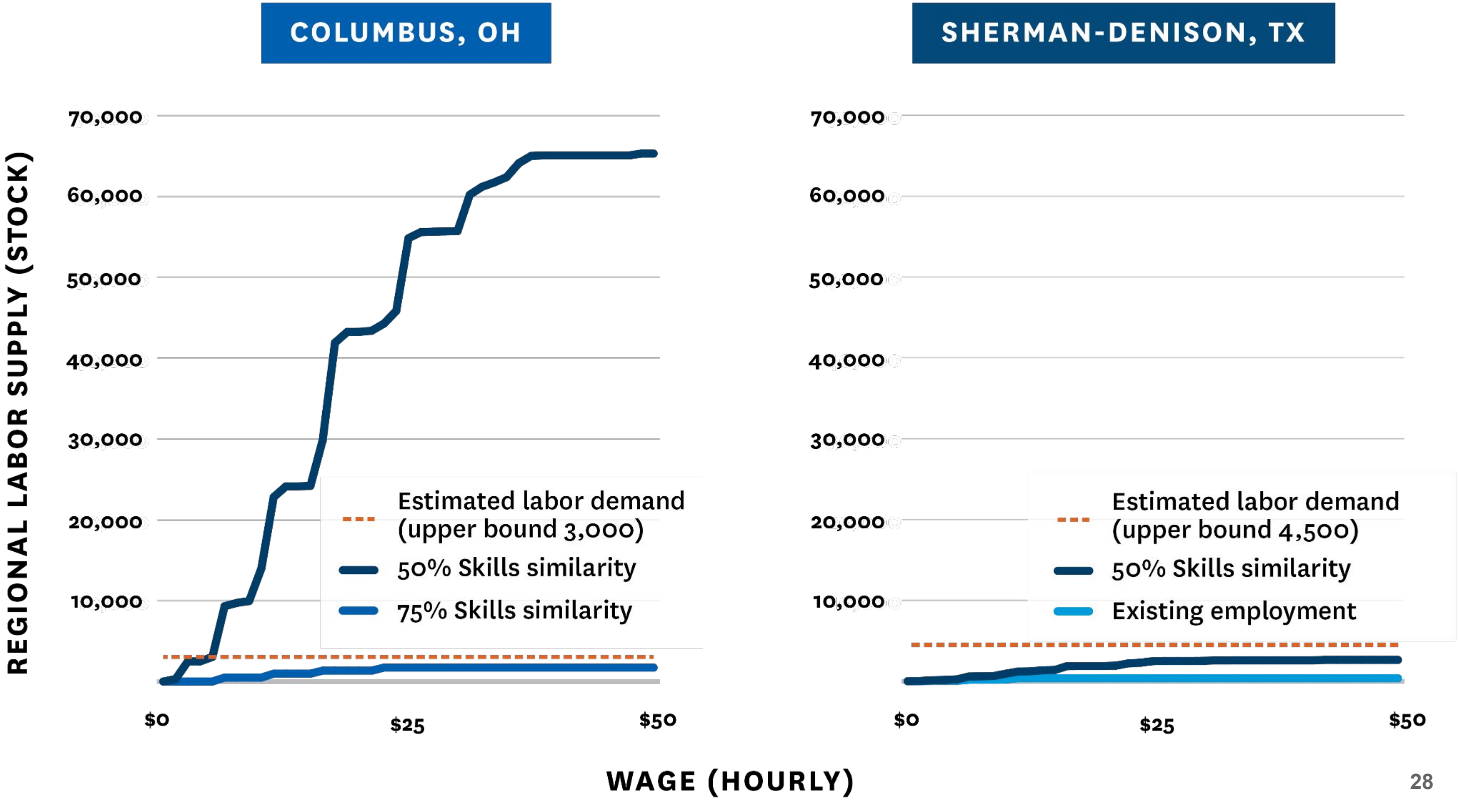
MOTIVATION

US strategic priorities in semiconductors face potential constraints:

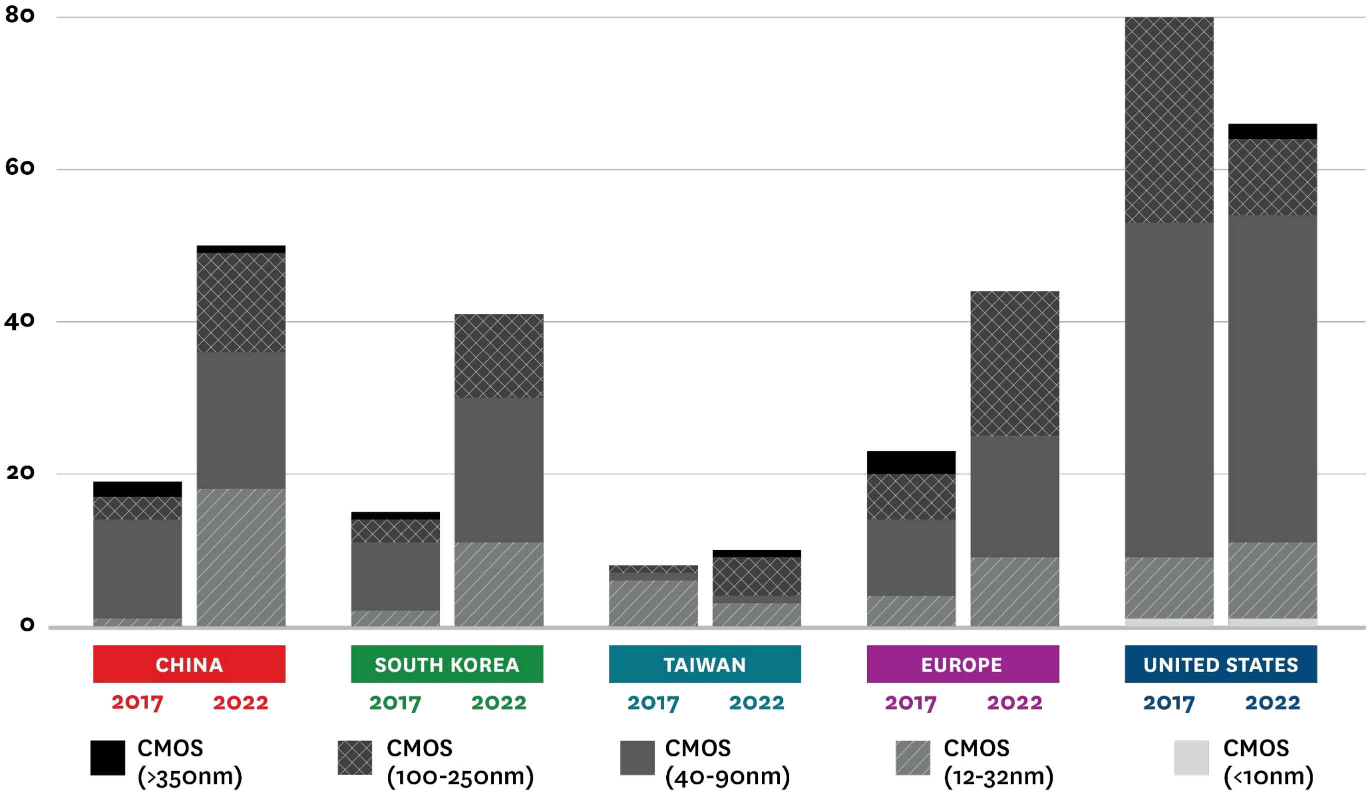
- **Production:** the US manufactures a declining share across all categories of chips and US leading-edge capabilities have fallen behind other countries, **risking access** for US industry and defense
  - Recapturing global market share and technology competitiveness requires addressing **skill demand-supply gaps**
- **R&D:** the US R&D ecosystem risks falling behind competitor nations as silicon-scaling and Moore’s Law slow down
  - International researchers have rapidly improving access to commercial facilities, critical to **accelerating discovery**
  - Rre-accelerate computing requires spreading capital across numerous candidate technologies to **catalyze commercialization**

Skilled labor availability in emerging production ecosystems is below estimated demand, and regional availability varies

EXAMPLE:
Semiconductor Processing Technicians



R&D leadership requires creating access for academic researchers to commercial production facilities

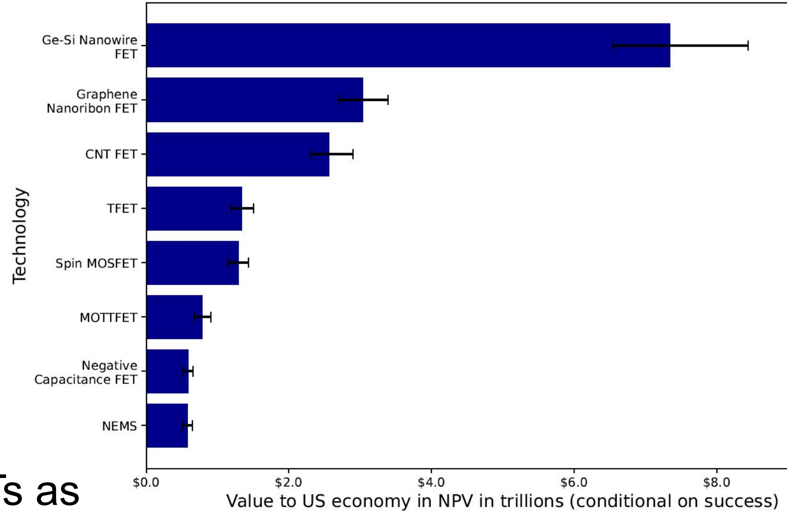


Economic competitors are **better equipping** academic researchers

With better access researchers can iterate on prototypes/designs at scale

Inventing the "Future of Computing" requires significant capital spread across numerous candidate technologies

The potential gains for the US economy are very large relative to the costs of prototyping and developing these devices.



- Unlikely any technology will replace CMOS in logic/computing within next decade
- It requires $100M to demonstrate a technology in conjunction with a mature CMOS platform; $1B to bring a technology to commercialization
- High uncertainty: initial benchmarking showed TFETs as most promising, progress stalled; CN-FETs took decades of investment to be ready to integrate with commercial-scale semiconductor processes
- Meanwhile China is closing the research gap in established (CMOS) and emerging (beyond CMOS) technologies

RECOMMENDATIONS

Successful implementation of public financing programs for domestic semiconductor production requires quickly closing skilled labor gaps

- Leverage **lightweight analytic tools** to identify **region-specific** skill supply-demand **gaps** (ideally prior to large-scale investment)
- Identify **occupations** with the right skill, wage and employment profiles **to transition into *new* occupations that meet demand**, and the supports (training, wraparound services) to encourage transitions

The US needs a coordinated and well-funded semiconductor R&D ecosystem to re-establish and maintain US technology leadership

- Policymakers should **incentivize firms -** as a condition of receiving subsidies for a US-based semiconductor facilities - **to improve their shuttle run and MPW offerings for US researchers**
- Policymakers should **increase funding for early and late-stage post-CMOS technologies beyond that in CHIPs** to best capture gains

BIOPHARMACEUTICALS DEMONSTRATION

Rena Conti

Marta Wosinska

EXPERT

What makes a drug critical?

What critical drugs have supply chain vulnerabilities, and thus access and quality issues?

Could advanced manufacturing technologies or policy help reduce supply chain vulnerabilities?

PROBLEM

ACCESS TO QUALITY PHARMACEUTICALS

PUBLIC

What is public perception of quality & access issues; able, willing to pay to improve?

Baruch Fischhoff

MOTIVATION

Pharmaceuticals are the most used medical care in the United States.

Yet pharmaceutical supplies are prone to disruption, which may result in quality deficits, shortages, & risks to health.

These challenges cause hardship for those who need the drugs, and can erode public trust in those responsible for their supply.

Advanced manufacturing technologies may help overcome challenges.

The U.S. government lacks a framework for assessing pharmaceutical criticality & vulnerability to support solutions.

THE WHITE HOUSE
WASHINGTON

BUILDING RESILIENT SUPPLY CHAINS, REVITALIZING AMERICAN MANUFACTURING, AND FOSTERING BROAD-BASED GROWTH

FDA U.S. FOOD & DRUG ADMINISTRATION

Accelerating the Adoption of Advanced Manufacturing Technologies to Strengthen Our Public Health Infrastructure

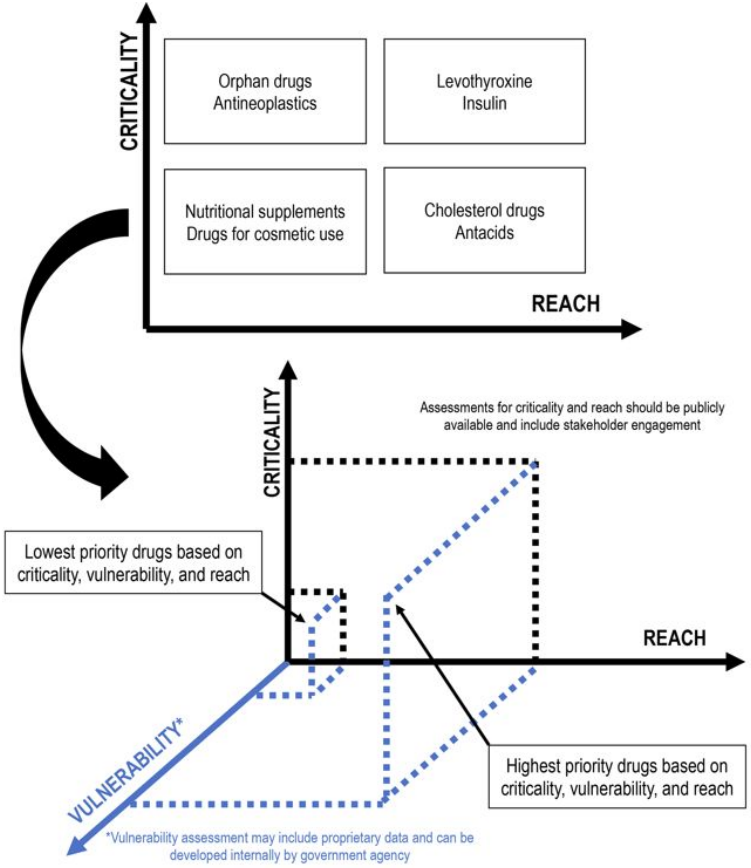
Findings

Advanced manufacturing technologies (AMTs)—such as continuous manufacturing, modular manufacturing, advanced batch processing, and digital twins—offer advantages in ensuring product quality and reliability of the manufacturing process.

- The private sector does not adopt AMTs; challenges related to economic incentives.

Private sector investment in resiliency will require government-supported situational awareness of vulnerabilities & improved incentives for adoption.

- But data is limited to assess vulnerabilities and prioritize improvements in vulnerable supply of critical pharmaceuticals most important to population health.*



*A Framework for Prioritizing Pharmaceutical Supply Chain Interventions www.healthaffairs.org/do/10.1377/forefront.20230912.938681

Health Affairs FOREFRONT

Public Acceptance

The public is widely aware of shortages, but lacks authoritative knowledge about their technical, market, and regulatory sources, such as the role of quality assurance and market concentration.

Distrust of medical industries colors public interpretation of shortages and proposals for change (e.g., price caps, rather than higher prices for AMTs).

Industry experts recognized the unmet need for monitor public concerns and proactively addressing them with authoritative communications

RECOMMENDATIONS

The federal government needs a multipronged approach, including:

- Revised regulation & alteration of other incentives to facilitate AMT development and deployment among pharmaceuticals.
- Systematic identification of critical pharmaceuticals & situational awareness of vulnerabilities to support & prioritize investments.
- Improved public communications of drug quality issues in fragile supply chains and early public input on expectations around quality, price, availability, and policies
- A dedicated body should be tasked with identification, situational awareness, prioritization, implementation & public communication to support pharmaceutical supply resiliency.

ENERGY & CRITICAL MATERIALS DEMONSTRATION

PROBLEM

FUTURE ACCESS TO CRITICAL MATERIALS FOR ELECTRIC VEHICLE BATTERIES

INTERVENTIONS

Policies and investment in innovation

DISCIPLINES AND METHODS

Scenario modeling of potential geopolitical and natural disruptions

Engineering models

Economic industrial organization models

Elsa Olivetti

Kate Whitefoot

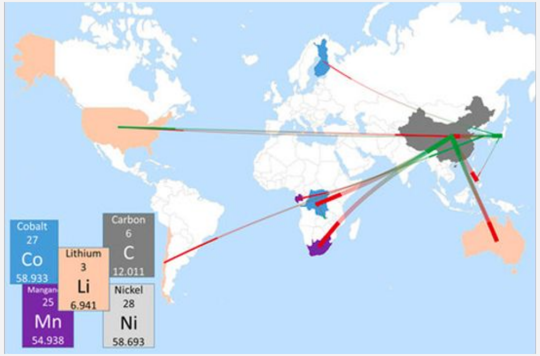
OUTCOME

Shortages, vehicle price increases, and worker job losses avoided

MOTIVATION

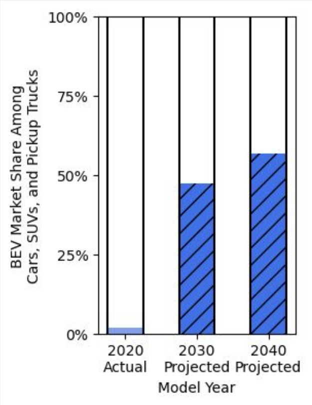
The needed transition from conventional to electric vehicles is likely to face significant battery material supply chain risks as early as 2030.

1



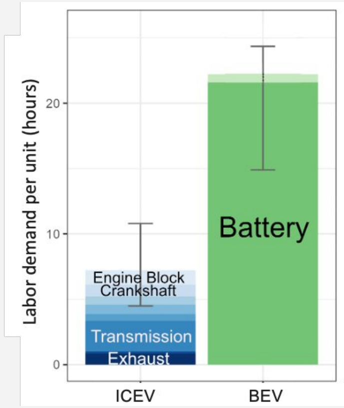
Olivetti, Ceder, Gaustad, Fu (2017)

2



Forsythe, Gillingham, Michalek, Whitefoot (2023)

3



Cotterman, Fuchs, Whitefoot (2022)

Critical Mineral Supply Shock Scenarios

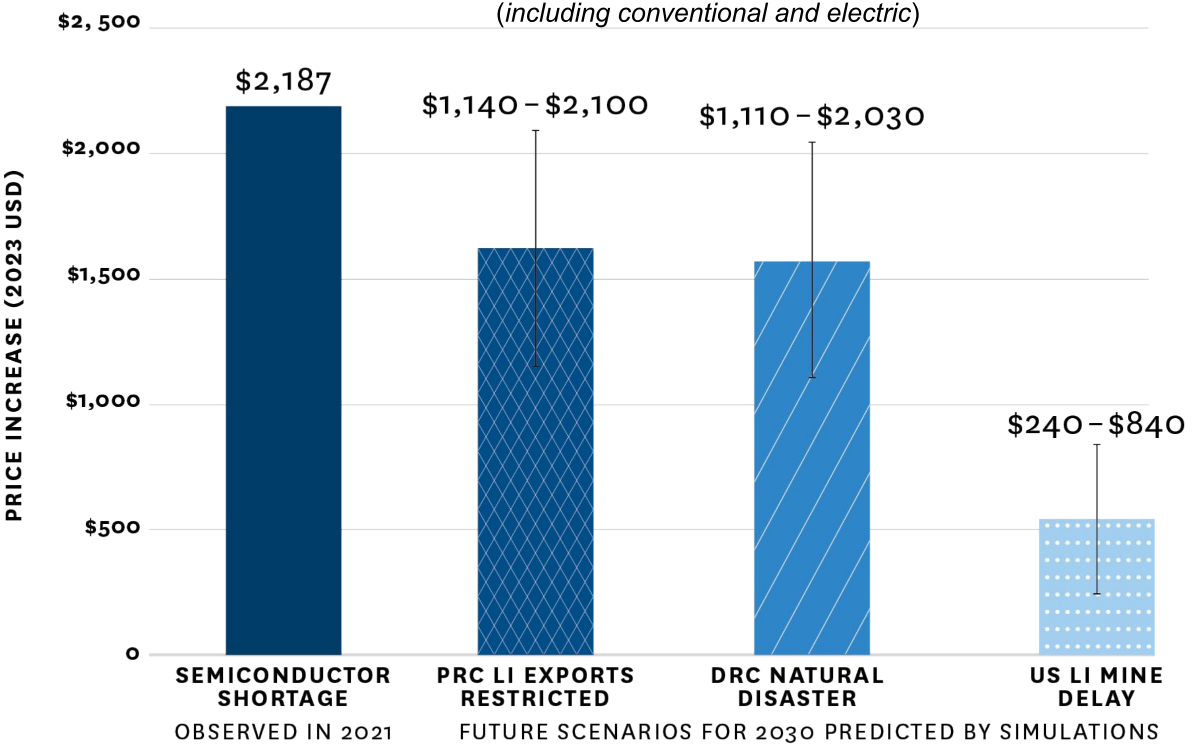
Scenario		Quantity	Estimated Resulting Median Material Price (2023 USD)	Estimated NMC811 Battery Production Cost (2023 USD)
Lithium	**Baseline**	2.8 Mt	$20,000/t LCE	$99/kWh
	PRC lithium export *restriction* causes 15% refined supply reduction	2.58 Mt	$80,000/t LCE	$126/kWh
	US lithium mine *delay* causes 250 kt raw lithium supply shortage	2.7 Mt	$40,000/t LCE	$108/kWh
Nickel*	**Baseline**	3.2 Mt	$20,000/t	$99/kWh
	Declining ore grades cause 800 kt raw supply *reduction*	2.4 Mt	$88,457/t	$138/kWh
Cobalt	**Baseline**	302 kt	$49,280/t	$99/kWh
	Human rights abuses cause 14% raw cobalt supply *reduction* to US	274 kt	$199,360/t	$110/kWh
	Natural disasters in the DRC cause 65 kt global raw cobalt supply *reduction*	258 kt	$479,360/t	$126/kWh
Graphite	**Baseline**	-	$10/kg	$99/kWh
	PRC export *restrictions* create significant reduction in natural graphite supply	-	$20/kg	$109/kWh

Supply shocks due to geopolitical disputes or natural disasters could have negative impacts similar to the semiconductor shortage

Impacts include:

- Significant price increases of new vehicles (both conventional and electric)
- Nearly 1 million US households unable to purchase a new vehicle
- $24B of consumer surplus losses
- Lost wages for battery cell and pack production workers

AVERAGE PRICE INCREASE OF U.S. NEW CARS
(*including conventional and electric*)



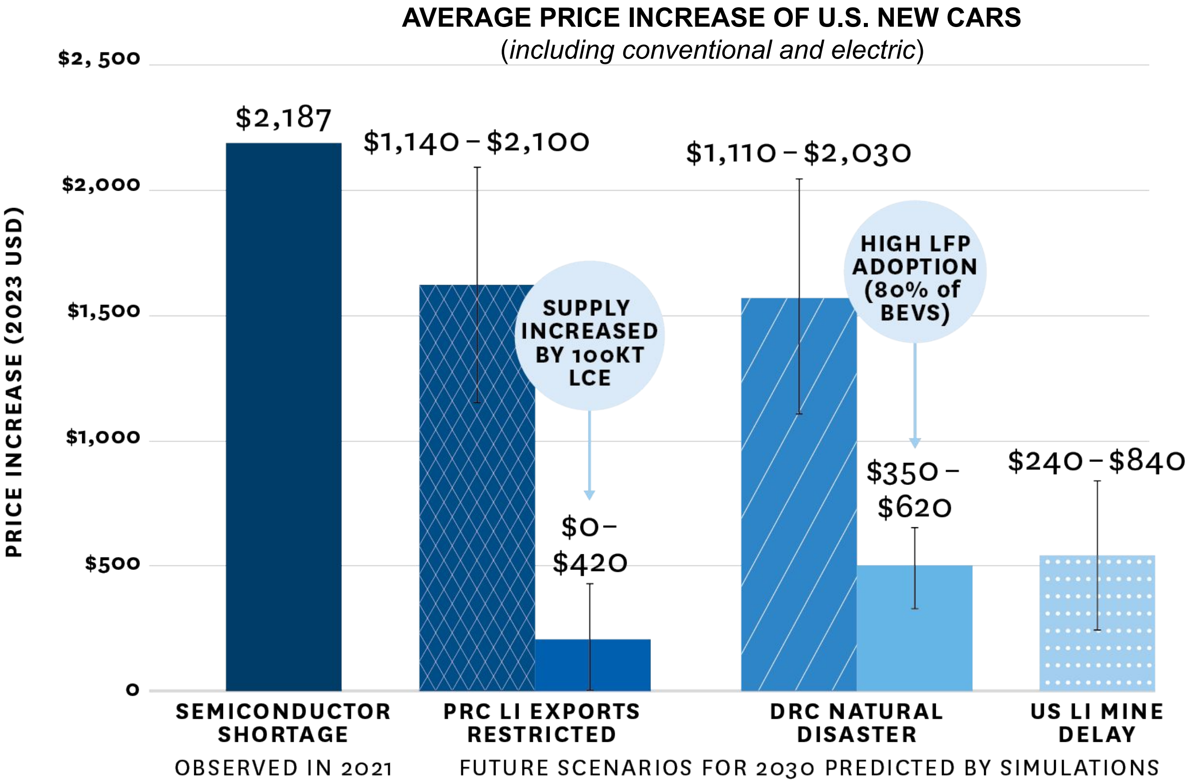
Vulnerabilities for U.S. households, workers from lithium and cobalt supply shocks can be reduced

Actions include:

- Increase lithium supply domestically or in locations with low geopolitical risk
- Use of cobalt-free batteries (e.g. lithium-iron-phosphate) in majority electric vehicles

Avoids:

- new vehicle price increases (conventional and electric)
- lost production worker wages
- ~1M households unable to purchase new vehicle



RECOMMENDATIONS

Immediate actions exist for increasing adoption of cobalt-free batteries and the future supply of lithium

Investments in innovations for:

- Cobalt-free battery performance,
- Supply-side technologies, such as direct lithium extraction

…would strengthen these alternatives

Cobalt-free batteries may also be more robust to longer use and high-speed charging, which could benefit lower income households that purchase used vehicles

Toward a Vision for Critical Technology Assessment

Advanced analytics can be used to inform:

US global competitiveness: situational awareness of global scientific capabilities, funding, and collaboration networks

US domestic capabilities: situational awareness of US domestic scientific capabilities, including funding biases

Technology commercialization pathways: policy, investment, and other interventions (technical, human capital, infrastructure, regulatory, and citizen awareness and participation) to overcome bottlenecks.

- Gaps in innovation infrastructure (existence, access)
- Skill gaps in specific regions and training interventions
- Public, technical, regulatory bottlenecks to new technology introduction

Supply chain vulnerabilities: the scale of their impact, innovation and policy interventions to reduce those vulnerabilities and impacts

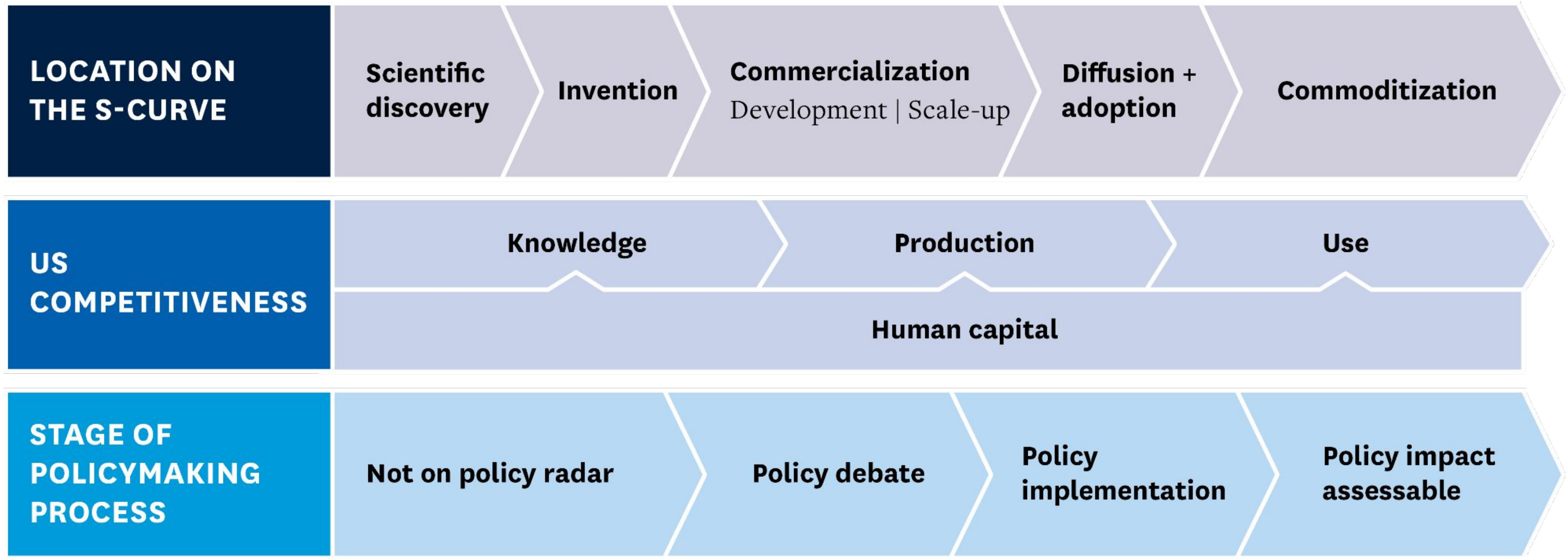
Toward a Vision for Critical Technology Assessment

Capabilities are hampered by the following gaps:

- **Situational awareness of global technology and production capabilities**
- **Timely data for rapidly moving critical technologies (such as AI)**
- **Timely data for critical supply chains**
- **Inclusion of equity in each analysis requires resources:**
  - Equity is not a single field of study: experts with complex analytic, technical, and phenomenological knowledge are needed to address issues in algorithmic bias, energy equity, health equity, and equity and discrimination in labor/training
  - Leadership is needed to ensure a cross-mission focus involving all three dimensions of criticality (security, the economy, social well-being), and that all analyses include the geographic and demographic implications

A Framework for Critical Technology Assessment

Dimensions drive methods, data needed, appropriate data solutions



A Framework for Critical Technology Assessment

Dimensions of criticality

1990 Defense Authorization Act defined “critical technologies” “essential for the United States to develop to further the long-term national security or economic prosperity.”

We define criticality along three dimensions

- US national security and that of our most dependable allies
- US economic well-being
- US social well-being

Timely, comprehensive indicators for these objectives can be challenging, but measures of these objectives relevant to strategic decisions are achievable and demonstrated throughout the report.

A Framework for Critical Technology Assessment

Dimensions drive methods, data needed, appropriate data solutions

WHY CRITICAL?	CURRENT STATE	FUTURE PREDICTED
High impact (on national missions if technology advances)	**Artificial intelligence**	**Semiconductors** (next-generation devices)
Anticipated vulnerabilities (if lacking access or leadership)	**Biotechnology** (generic drug access)	**Energy storage and critical materials**

TYPE OF TECHNOLOGY ASSESSMENT

- Identified bottlenecks to commercialization and potential benefits
- Quantified benefits for productivity, labor of greater geographic and demographic distribution
- Quantified economic benefits of mitigating future vulnerabilities
- Identified interventions to reduce vulnerabilities in access to current products

INCREASES IN DISCOVERY, DIFFUSION, ADOPTION

A Framework for Critical Technology Assessment

Dimensions drive methods, data needed, appropriate data solutions

RELEVANT DATA

- placement in the critical technology assessment framework, particularly stage of S-curve and data availability
- characteristics of the technology and its industrial organization
- research question

RELEVANT DATA SOLUTIONS

Stage of S-curve	Data Availability	Data Solution
Earlier	More Public Data	Observatory
Later	Less Public Data	Trusted 3rd parties, public-private partnerships, data trust

MORE DATA ISN'T ALWAYS BETTER

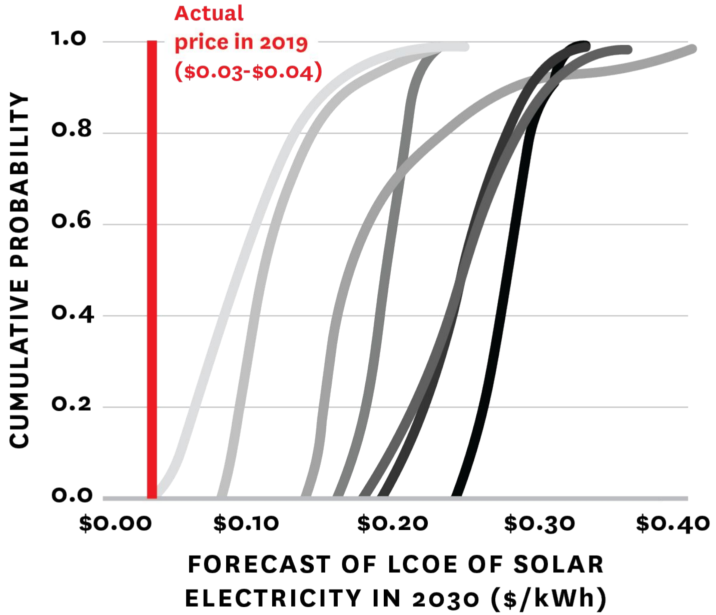
Can be trade-offs between timeliness, frequency, accuracy, completeness, granularity, privacy, access, costs.

A Framework for Critical Technology Assessment

Forecasting Technology Outcomes

- Technology forecasts involve complex technological and social systems whose interactions and outcomes can be difficult to predict
- For useful predictions to be possible, stable patterns must exist
- Forecasting of *exact times of precise technical developments* should not be the primary focus of near-term critical technology assessment efforts
- Predictions of the *general direction(s)* in which technology will change and analyses of what will be the gating factors in these technological advances (and actionable policy interventions) require much less precision, and taken with appropriate caution, can be of great use in guiding decision makers.

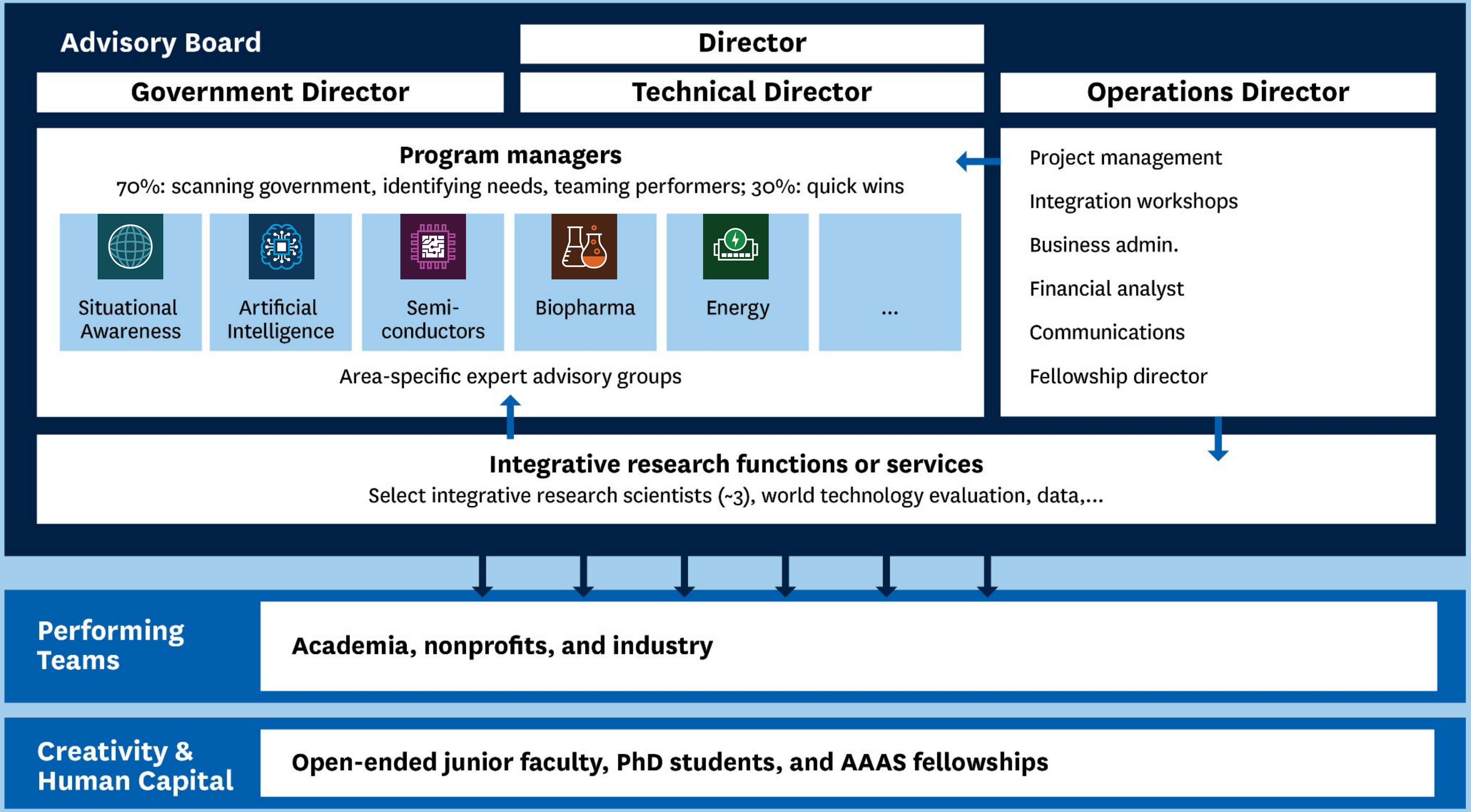
Expert forecasts in 2009–10 of likely solar electricity prices in 2030



Adapted from Savage et al. (2021)

Analytics to Inform National Technology Strategy

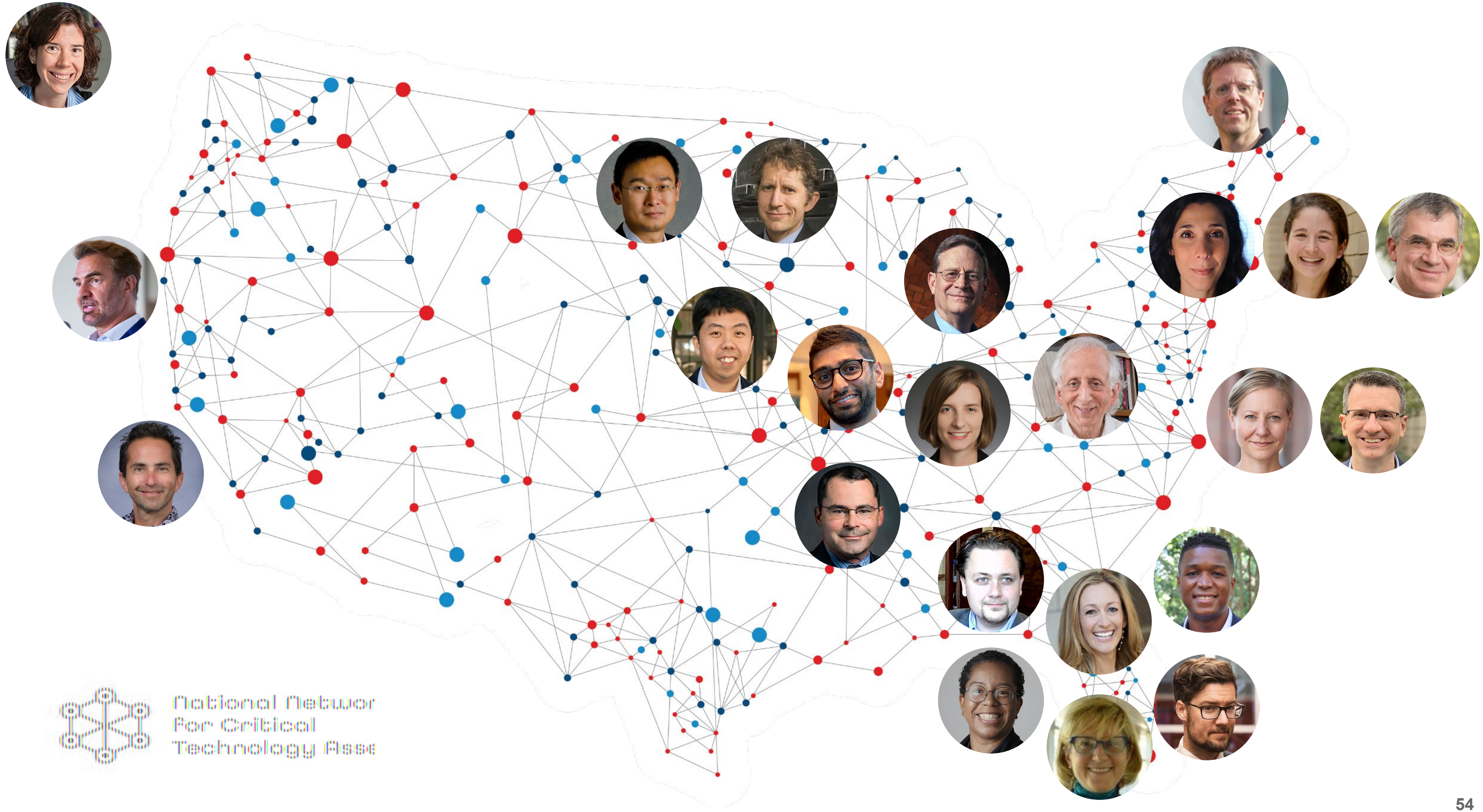
- Be **strategic and forward-looking**
- Leverage **integrated, interdisciplinary teams**
- Focus on **problems at the intersection of departmental missions**
- Serve as a **neutral third party**
- Operate in a **highly flexible, distributed model** capable of rapidly mobilizing and reconfiguring star private sector, government and academic talent, data, and resources


Advisory Board
Director
Government Director
Technical Director
Operations Director
Program managers
70%: scanning government, identifying needs, teaming performers; 30%: quick wins
Situational Awareness
Artificial Intelligence
Semi-conductors
Biopharma
Energy
...
Area-specific expert advisory groups
Project management
Integration workshops
Business admin.
Financial analyst
Communications
Fellowship director
Integrative research functions or services
Select integrative research scientists (~3), world technology evaluation, data,...
Performing Teams
Academia, nonprofits, and industry
Creativity & Human Capital
Open-ended junior faculty, PhD students, and AAAS fellowships

The CHIPS and Science Act calls for a new federal capacity to fortify the nation’s leadership and ability to determine policies and investments that will ensure national security, global competitiveness, economic prosperity, and social well-being.

To operationalize this mandate the US will need to intentionally design a rapid Critical Technology Assessment function

- Synthesize and integrate distributed capabilities, analytic power, and technical expertise across the nation's rich variety of institutions and disciplines
- Led by a single organizational unit charged to:
  - think across national missions and technology interdependencies
  - engage topic-specific program managers trained in the "art" of
    - identifying the most important problems
    - matching methods to problems
    - mobilizing and orchestrating the distributed national capabilities both within and outside government.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