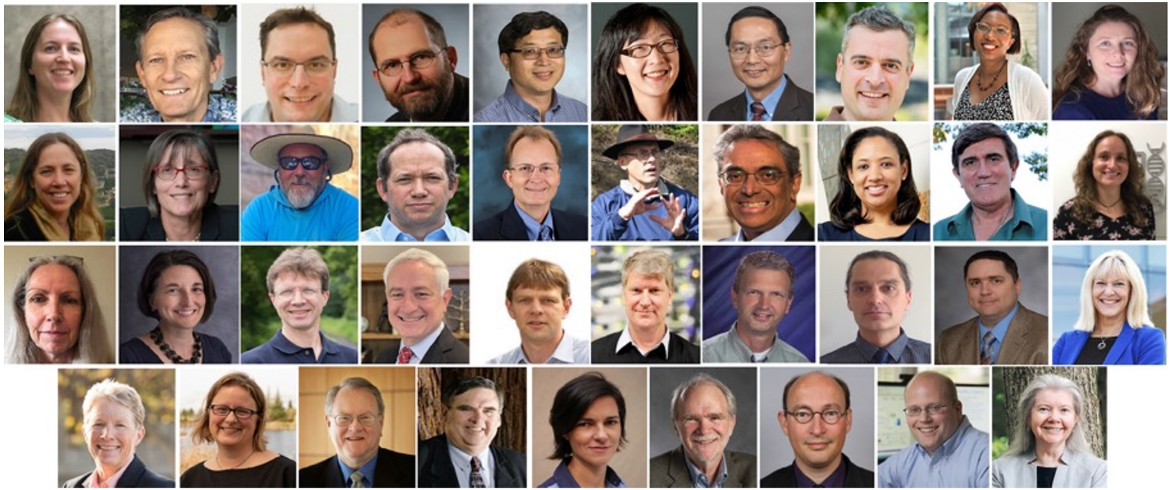
U.S. Scientific Leadership Addressing Energy, Ecosystems, Climate, and Sustainable Prosperity

BERAC Subcommittee on International Benchmarking

Fall BERAC Meeting, October 13th, 2022

BERAC Subcommittee on International Benchmarking



Co-Chairs: Maureen McCann and Patrick Reed

Working Group Co-leads: Crysten Blaby-Haas, Kate Calvin, Allison Campbell, Brian Davison, Bob Fischetti, Ann Fridlind, Michael Gooseff, Kerstin Kleese van Dam, Kristala Jones-Prather, Jerry Meehl, Himadri Pakrasi, Gary Stacey, Margaret Torn, John Weyant, Shaocheng Xie, Huimin Zhao

Working Group Members: Ana Alonso, Ludmilla Aristilde, Kenneth Davis, Ben Evans, Efi Foufoula-Georgiou, Serita Frey, Ramon Gonzalez, Nathan Hillson, Janet Jansson, Klaus Keller, Markus Kleber, Costas Maranas, Jennifer Pett-Ridge, Johannes Quaas, Sue Rhee, Phil Robertson, Alistair Rogers, Tim Scheibe, Thomas Schneider, Detlef van Vuuren, Stan Wullschleger

Many thanks to our support team!


- Tris West
- Wayne Kontur

- Chloe Freeman
- Holly Haun
- Jessica Johnson
- Julia Johnson
- Jackie Kerr
- Marilyn Langston
- Stacey McCray
- Marissa Mills


- Mary Beth West
- Josh Nelson

- Andrew Flatness

Charge letter questions to BERAC

- Within the BER-supported topical research areas and facility capabilities, in which areas and capabilities, presently or in the foreseeable future, does BER lead in the international community, and in which areas does leadership require strengthening? In identifying these areas, please consider their critical mission relevance, recent history, the status quo, observable trends, and evidence-based projections.
- Are there key international partnerships that could strengthen BER science output and increase global visibility of BER?
- To preserve and foster U.S. leadership with resource constraints, is there a preferred optimization for organizing research, collaboration, and funding mechanisms among labs, universities, and other federal agencies? Are there other key efficiencies and balances that should be considered and modified to improve U.S. leadership in BER research areas?
- For someone deciding whether to pursue a scientific career, or a mature scientist considering whether to stay in the U.S., how can BER programs and facilities be structured and managed to create incentives that will attract and retain talented people? What are the key opportunities for BER in attracting and enhancing careers in BER-supported science?

Approach to metrics

Our goal is to benchmark performance in the last decade and to be generative for BER's strategy in the next decade with **actionable** recommendations.

- **Quantitative metrics** (bibliometric data, programmatic funding): used for benchmarking BER's practices, structures, protocols and resource investment, products and outcomes
- **Qualitative metrics** (over 60 interviews with thought leaders, Town Halls, public request for information (RFI)): used for assessing the potential for international leadership in the next decade

With inputs from international thought leaders and RFI responses, hypotheses emerged that were tested in Town Hall meetings and discussed with subject matter experts and across the full Subcommittee. In some cases, quantitative metrics provided supporting evidence for a hypothesis.

- We report both consensus and disagreement

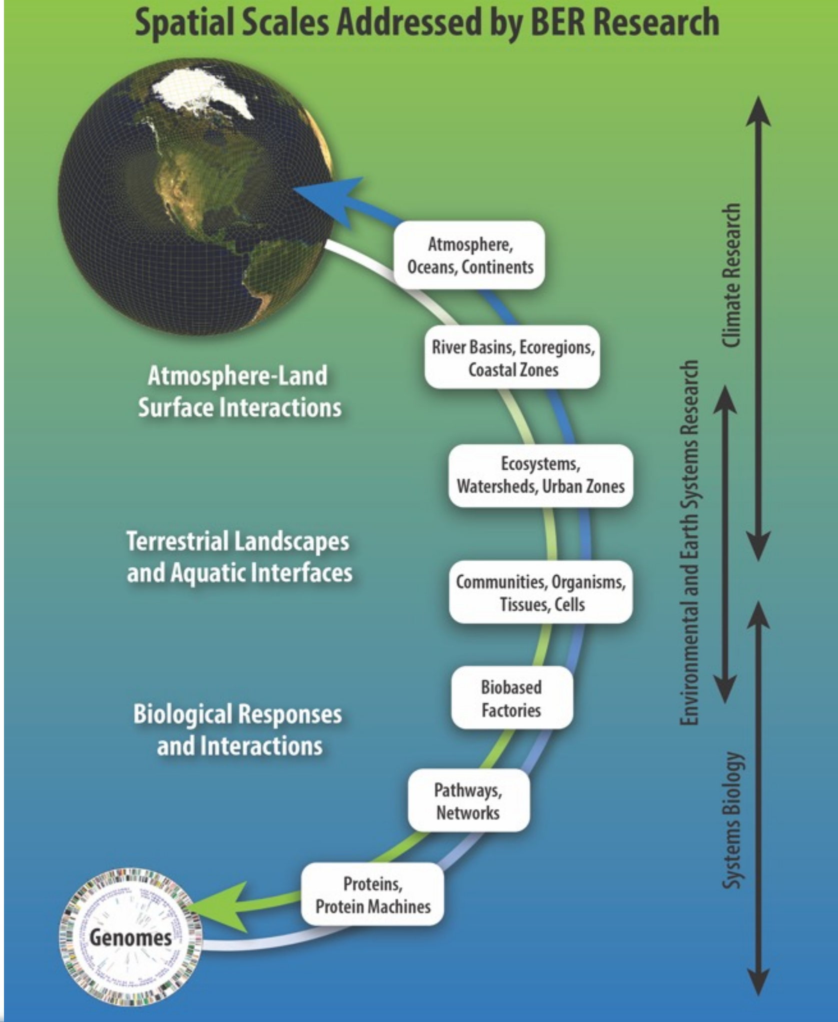
Report Outline

Executive summary

1. **Introduction**
2. **Bioenergy and Environmental Microbiomes**
3. **Biosystems design**
4. **Environmental Science**
5. **Climate Science**
6. **Enabling Infrastructure**
7. **Integrative Science**
8. **Strategies for people, partnerships, and productivity**

Reflections and Conclusions

Appendices A to G Key Findings and Recommendations; BERAC members; Approach to Metrics and Methodologies; Request For Information; References; Image credits; Acronyms and Abbreviations



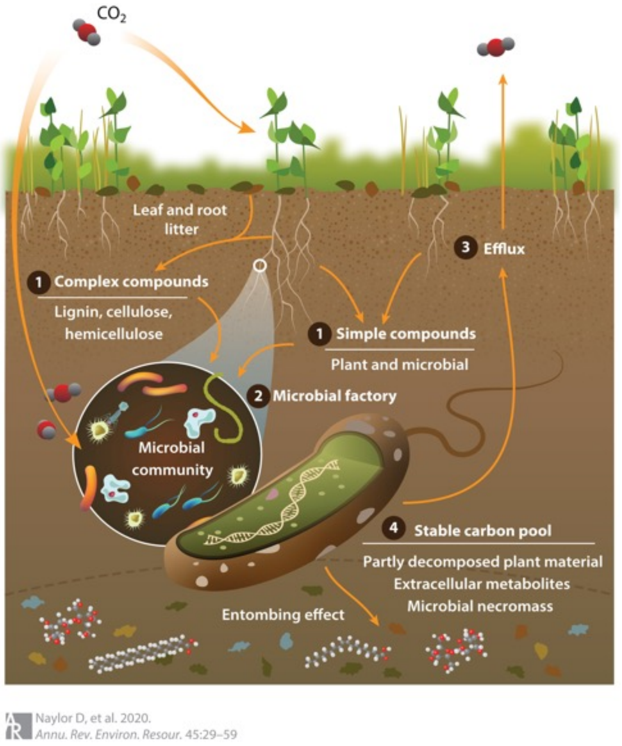
Example of a Chapter-specific recommendation

Build on internationally recognized strengths and leadership in genome-enabled knowledge in bioenergy and environmental microbiome research areas to understand the complex interactions between bioenergy crops and environmental microbiomes.

- The BER research portfolio has the people and tools needed to form large-scale research teams who in partnership can build a holistic, multi-scale, predictive understanding of sustainable bioenergy cropping systems, their microbial communities, soil health, and ecosystem-level processes.

Outcome:

Management of ecosystem sustainability for an environmentally sustainable bioeconomy in the face of a changing climate.



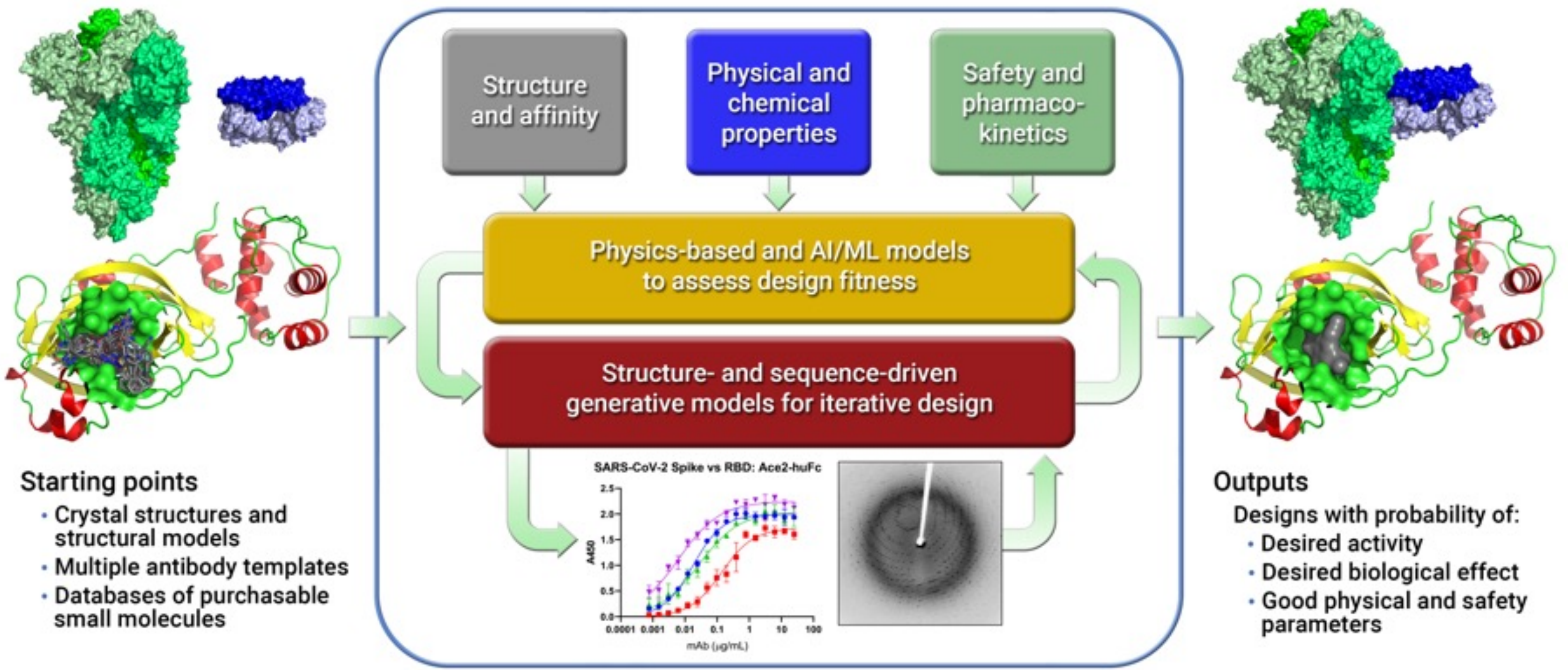
Leveraging systems biology approaches to gain predictive understanding of above- with below-ground communities for an environmentally sustainable bioeconomy

Case Studies

Title	Mission area	Takeaways
DOE Bioenergy Research Centers	Bioenergy and Environmental Microbiomes	Well-managed, mission-inspired scientific centers can be successful, and sustained collaborative funding can increase research impacts.
From Biofuels to Bioeconomy—DOE Funding Helps Gingko Develop Leading Cell Programming Platform	Biosystems Design	DOE-funded workforce training outside of PhD tracks (e.g., associate degrees, apprenticeships, and certificates) is essential for the future bioeconomy.
Amyris—Delivering on the Promise of Synthetic Biology	Biosystems Design	Partnerships with R&D companies can amplify BER research impacts and bring BER-relevant processes to scale for market impact.
Next-Generation Ecosystem Experiments	Environmental System Science	Explicitly connecting understanding of ecosystem processes to Earth system modeling is a paradigm shift in the integration of modeling, experimentation, and observations.
IDEAS—Interoperable Design of Extreme-scale Application Software	Environmental System Science	A community approach has enabled leadership in the computational modeling of terrestrial and watershed ecosystems with high process fidelity at various spatial scales.

Title	Mission area	Takeaways
CMIP—Coupled Model Intercomparison Project	Climate Science	BER support of and leadership in CMIP has been vital to the project's far-reaching success in the international climate science community.
Cloud Feedbacks and Climate Sensitivity	Climate Science	BER is a world leader in understanding how clouds affect Earth's energy budget, how and why their properties shift under climate change, and how sensitive Earth is to carbon dioxide.
The National Virtual Biotechnology Laboratory—DOE's R&D Response to COVID-19	Enabling Infrastructure	An enabling infrastructure coupled with diverse capabilities can be leveraged for a rapid, impactful response to national needs or emergencies.
Can BER Influence National Laboratory Culture to Attract Great Talent?	People, Partnerships, and Productivity	DOE and the national laboratories need to prioritize, with time and investment, workforce development.
MOSAiC—Multidisciplinary Drifting Observatory for the Study of Arctic Climate	People, Partnerships, and Productivity	The Atmospheric Radiation Measurement user facility demonstrated BER's key leadership in an international partnership by operating a major component of the largest arctic scientific expedition in history involving more than 80 research institutions from 20 countries.

Example of a Case Study

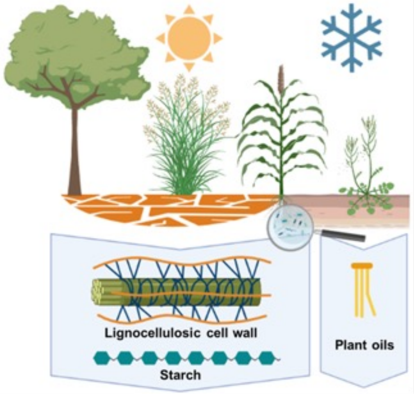


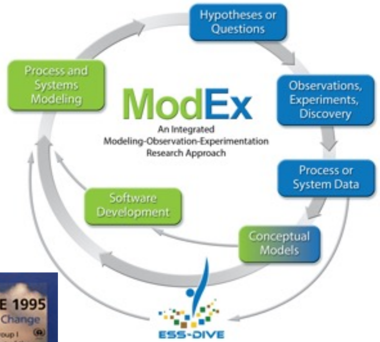
Enabling Infrastructure Case Study: COVID-19 #NatLabsInTheFight

Overarching findings - strengths

- BER's international leadership is well-substantiated across mission areas and enabling infrastructure
- Mission areas increasingly target the critical challenges of the coming decades for which Big Science can and must be entrained
- International leadership is a more meaningful goal when viewed in a collaborative versus adversarial context
- Future leadership is not guaranteed and will require increased investments and strategic partnerships with private, public, and academic institutions; other DOE programs; other federal agencies; international collaborators; and across disciplines

Substantiated international leadership across BER mission space

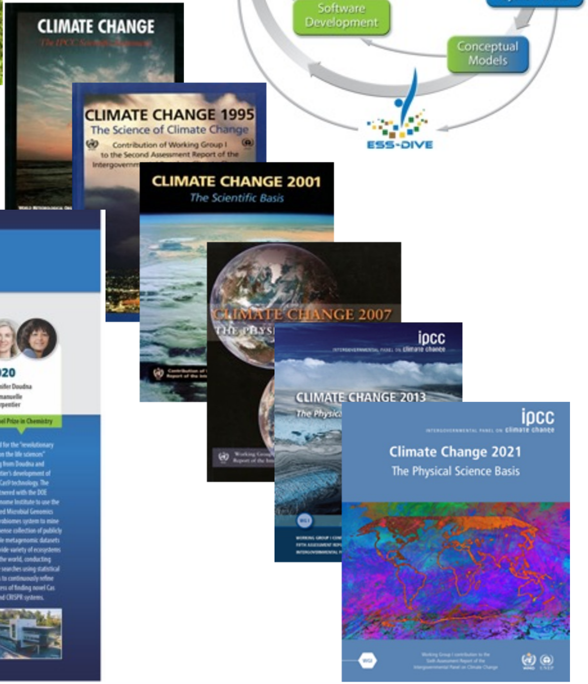




DOE Bioenergy Research Center Strategies at a Glance

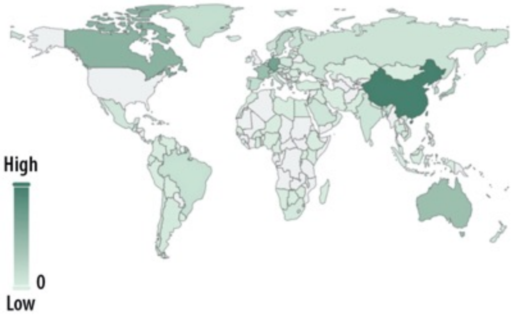
Overcoming the critical basic science challenges to cost-effective production of biofuels and bioproducts from plant biomass requires the coordinated pursuit of numerous research approaches to ensure timely success. Collectively, the DOE Bioenergy Research Centers provide a portfolio of diverse and complementary scientific strategies that address these challenges. These BRC strategies are listed briefly below.

	Sustainability	Feedstock Development	Deconstruction and Separation	Conversion
CABBI	Integrate spatially explicit economic and environmental analyses for a sustainable bioeconomy	Develop "plants as factories" for sustainable and resilient production of biofuels and bioproducts	Develop industrially relevant process and extraction technologies for feedstock oils and sugars	Establish artificial intelligence/machine learning–driven biofoundry for biofuels and bioproducts
CBI	Optimize water and nutrient use for high-yielding bioenergy crops with improved soil carbon storage	Create process advantaged bioenergy crops exploiting natural genetic variation found in feedstock plants	Advance integrated and consolidated bioprocessing with co-treatment	Generate drop-in biofuels (i.e., sustainable aviation fuel) and bioproducts from biomass and lignin residues
GLBRC	Conduct long-term studies of growing bioenergy crops on bioenergy lands	Design productive and high-value bioenergy cropping systems	Develop cost-effective biomass deconstruction and separation strategies	Identify and engineer novel biomass conversion microbes
JBEI	Design sustainable and cost-effective bioenergy cropping systems and conversion processes	Engineer bioenergy crops for high yield, environmental resilience, and efficient conversion into biofuels and bioproducts	Develop and demonstrate affordable feedstock-agnostic biomass deconstruction technologies based on ionic liquids	Develop high-throughput biosystems design tools and microbial hosts for scalable, carbon-efficient biofuels and bioproducts

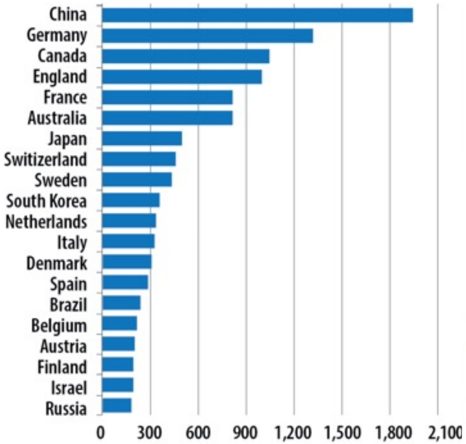


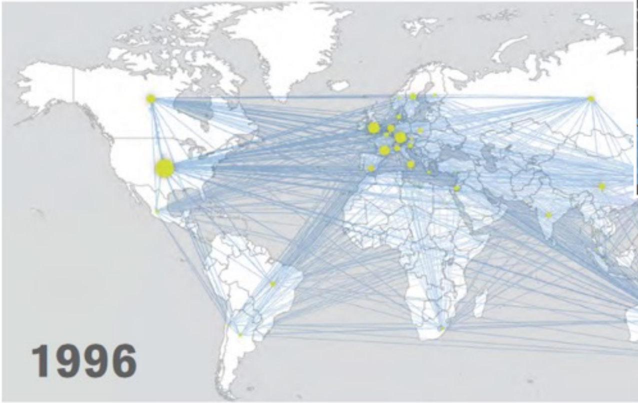
In a global research community, we are interdependent on others for our national success

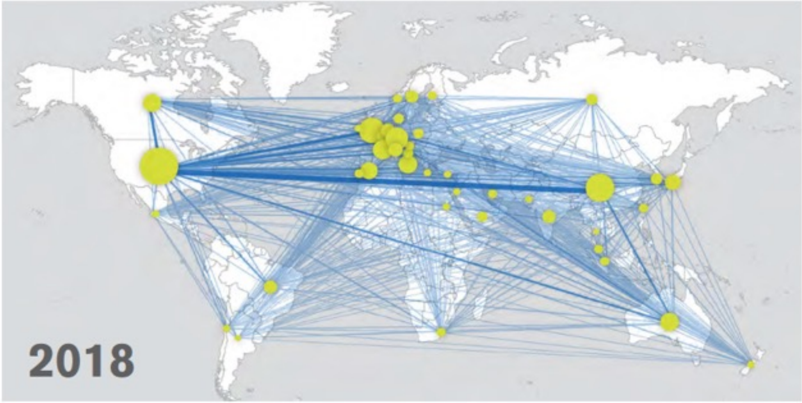
Co-Authorship Collaborations by Country



Top 20 Countries by Publication Volume



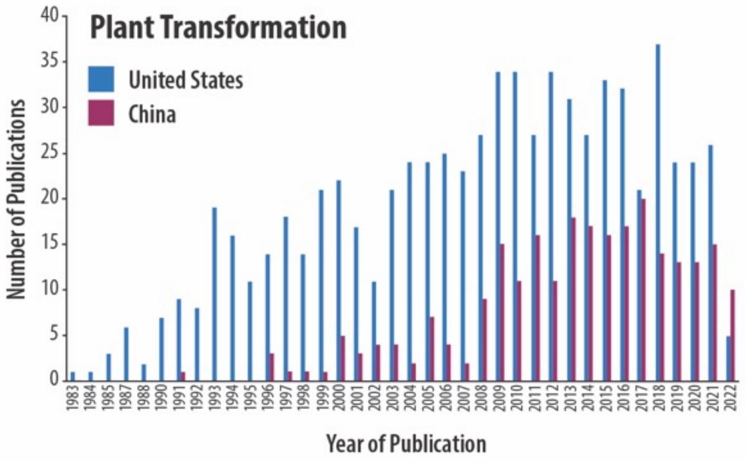


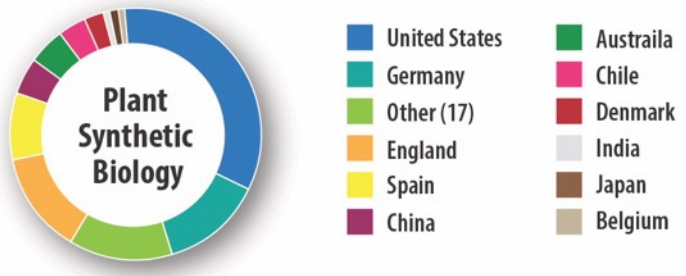


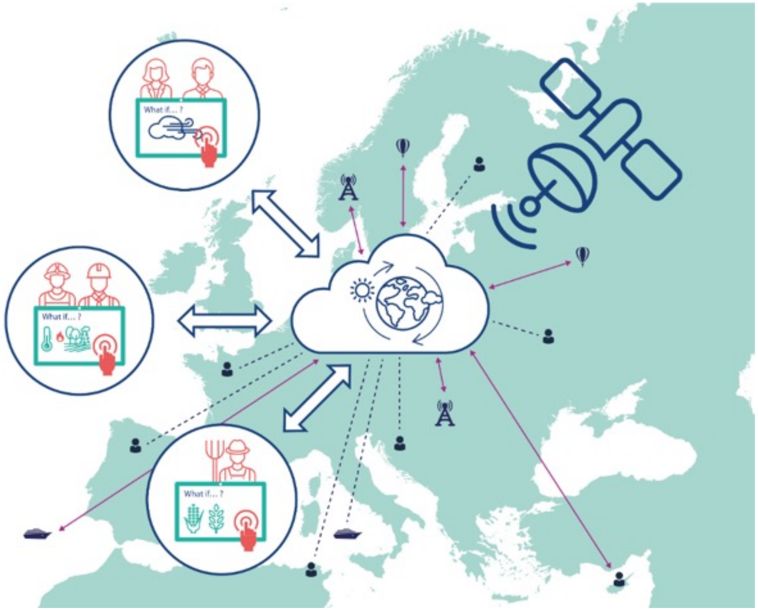
- Joint publications with international co-authors are highly cited
- Numbers of international collaborations have increased together with the magnitude of the global research enterprise

Future leadership is not guaranteed

- Mission-specific search terms reveal other countries catching up to the U.S.





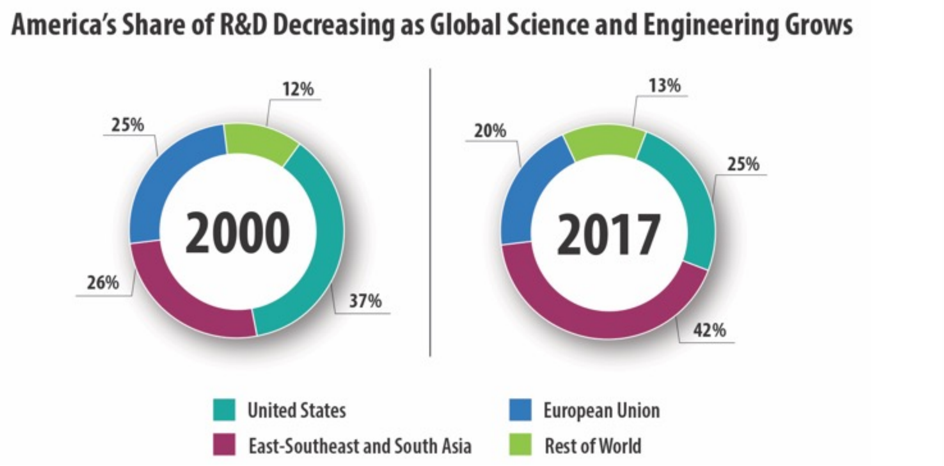


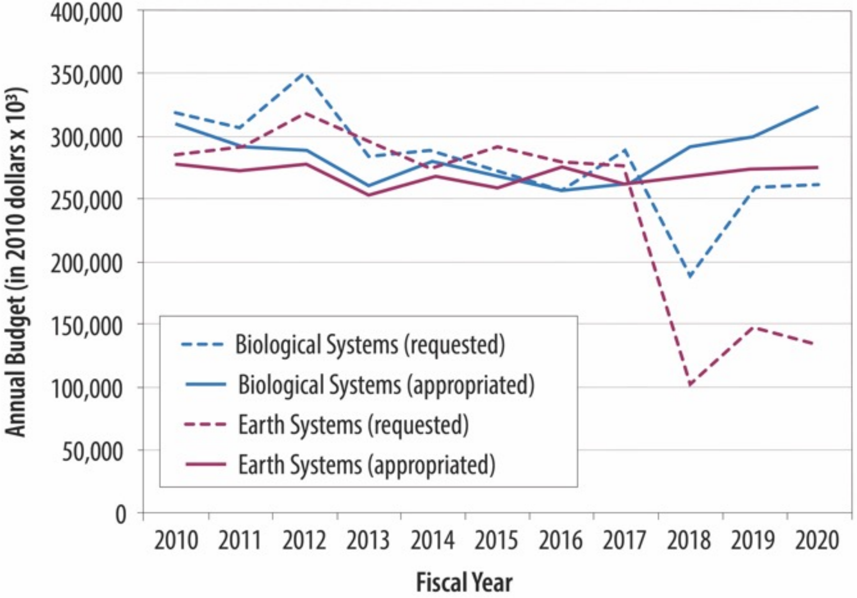
- Destination Earth (DestinE) is a major new integration initiative of the European Commission, with ≈$500M committed over the first 7–10 years to develop a high precision digital model of the Earth

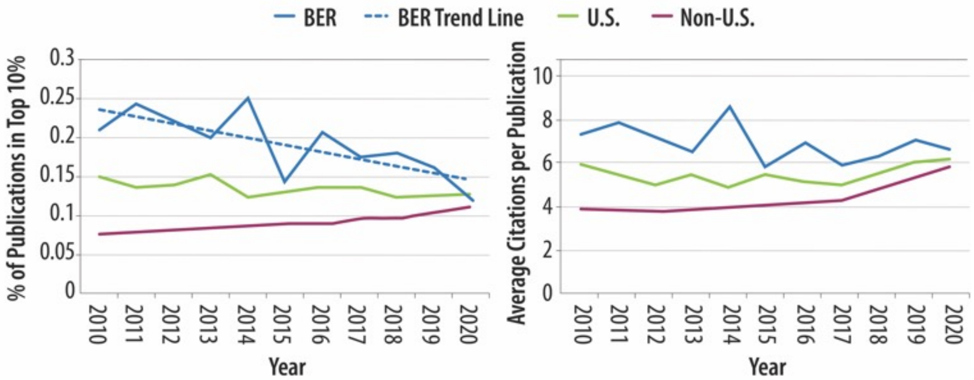
Overarching findings - concerns

- Volatility in priorities, funding, and workforce retention significantly threaten BER's ability to sustain its leadership
- BER's funding over the last decade has not increased commensurately with the growing scale and acuteness of the national and global challenges that BER missions and science address
- The science community does not widely associate BER with the major research impacts and achievements it has enabled

Volatility, flat funding, and lack of visibility are threats



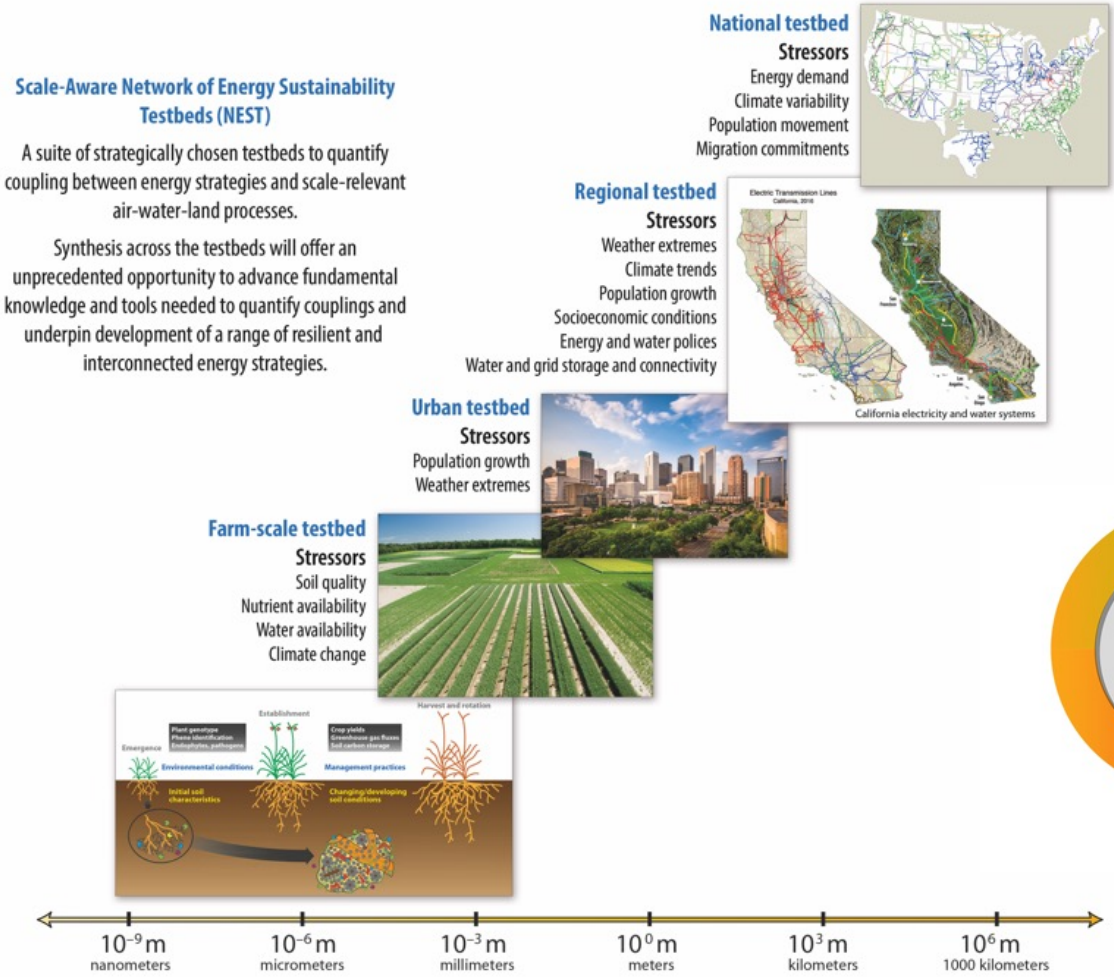




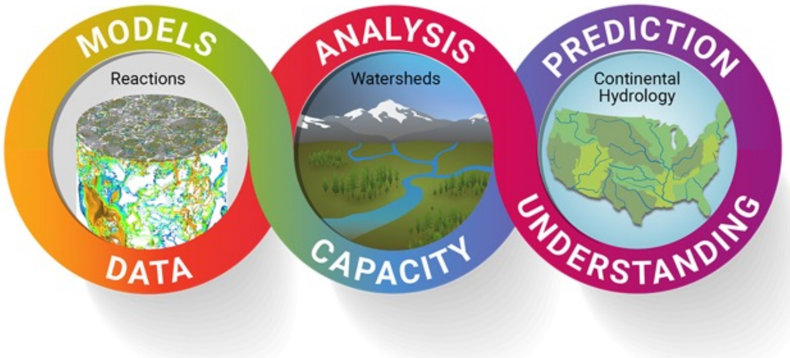
Overarching Recommendations

- Increase and sustain needed resources in all mission areas and in integrative science opportunities across and between these areas (**risk: failure to invest**)
- Improve connection between basic science and research across technology readiness levels (**risk: failure to capitalize on investment**)
- Establish horizon-scanning mechanisms for long-range, strategic infrastructure and mission-area investments (**risk: failure of imagination**)
- Elevate the stature of BER mission science to ensure recruitment of the best and brightest (**risk: failure to inspire**)
- Prioritize, with time and investment, a culture that supports diversity and inclusion, enables early- and mid-career professional development, and delivers the future workforce (**risk: failure to sustain future leadership**)

Opportunities for integrative science



- We applaud BER’s investment in the BRCs and in the Integrated Field Laboratories program
- BER could consider synergies between BSSD and EESSD

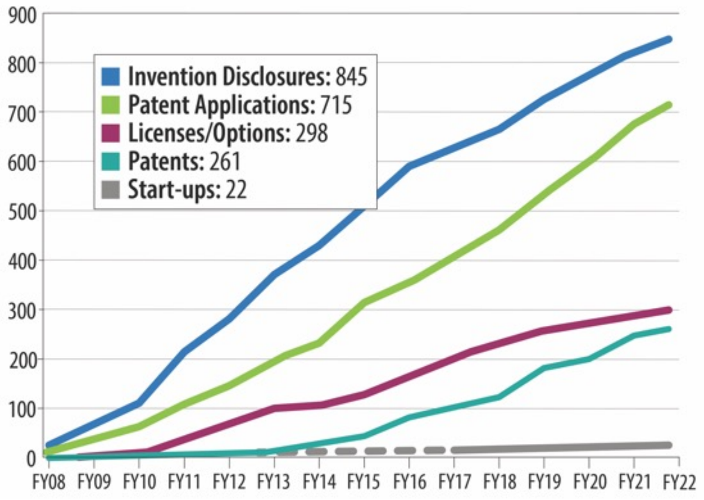


Entrain basic science to research across TRLs

Patents as Proxies for Innovation

Agency*	Patents Per $100 Million Funded
DOE total	8
DOE Bioenergy Research Centers (2007 to 2021)	21
National Science Foundation	11
National Institutes of Health	5
U.S. Department of Agriculture	5
U.S. Department of Defense	2.5

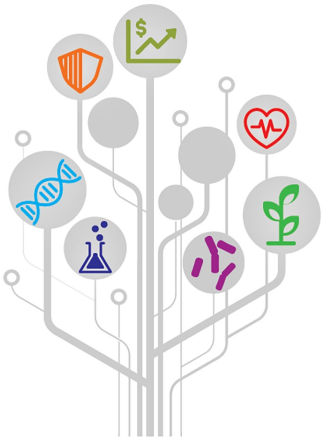
** All agencies 2000 to 2013 except as noted. Source: NIH 2015.*



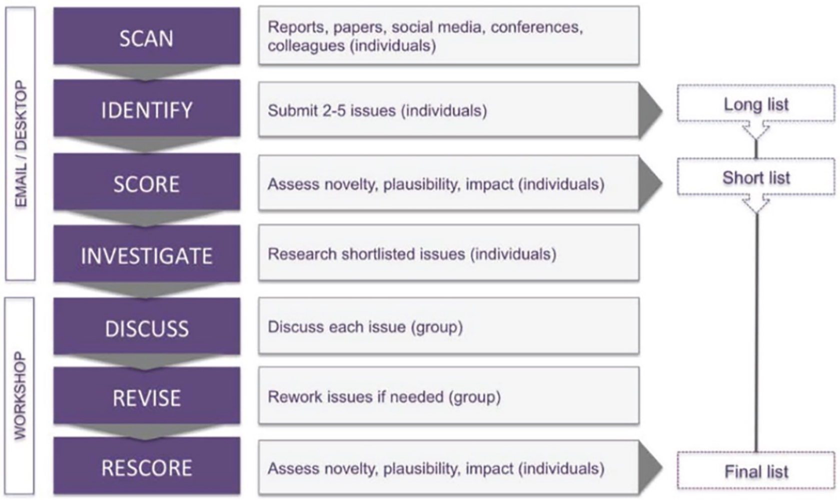
https://doi.org/10.1038/s41587-021-01195-w (2022)

- Even in the innovation ecosystem of the Bioenergy Research Centers, it has proven difficult to translate discovery to market impact
- The pace of discovery is accelerating and should compress the time spent at TRL 1-5 for technology development and deployment

Establish horizon-scanning mechanisms



- Respondents and subcommittee applaud BER emphasis on a research community approach (roundtables, workshops, NASEM reports)
- However, as the research enterprise becomes increasingly globalized, BER needs mechanisms to increase its agility to respond to breakthroughs
- The program can take advantage of proven methodologies in horizon-scanning and foresight exercises

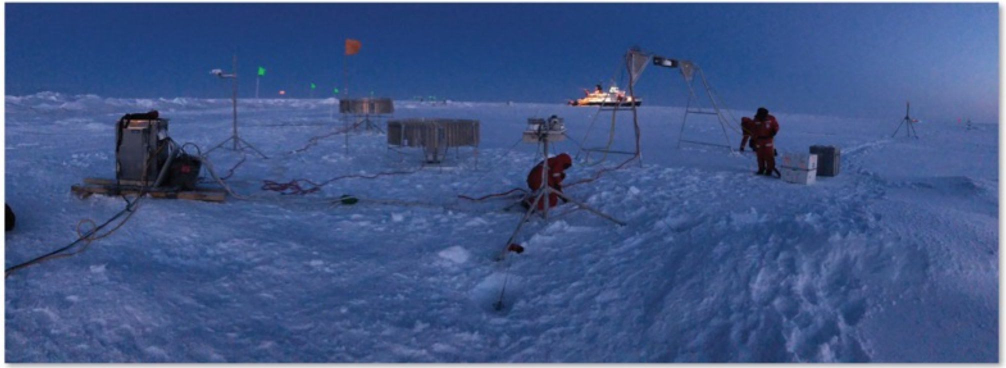


Ch 6 in http://nap.nationalacademies.org/25525

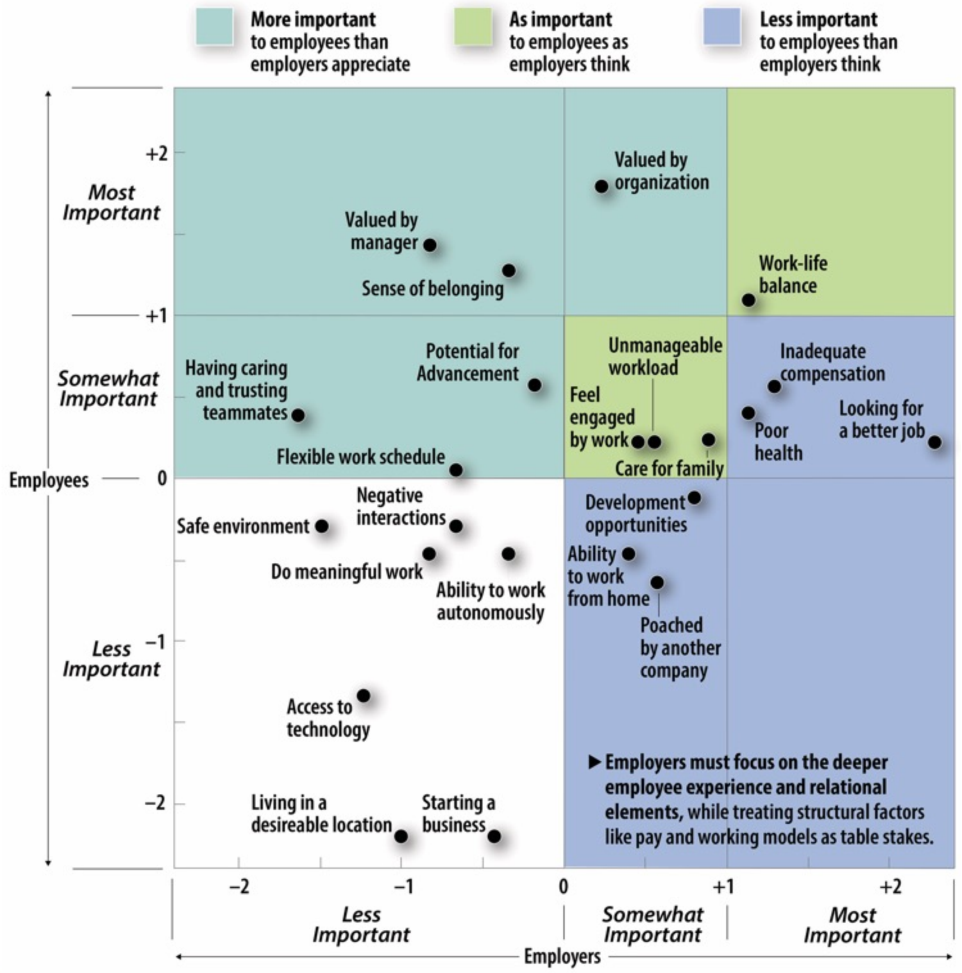
Elevate the stature of BER mission science

- Need to better communicate inspirational science accomplishments to ensure recruitment of the best and brightest

- Critical for attracting academic researchers to dedicate their careers to BER science



Prioritizing a culture that supports the future workforce



- In the future of work, employers might attract and retain employees by focusing on relational, not transactional, aspects of their culture
- BER and DOE should consider how to influence the culture and climate across the national laboratory system to promote inclusivity, improve opportunities for personal and professional development, and mitigate sources of stress and anxiety

Figure re-drawn from De Smet, Dowling, Mugayar-Baldocchi, Shanninger “Great attrition or great attraction – the choice is yours” McKinsey Quarterly, September 2021

For the coming decades, BER mission areas have a critical role at the nexus of global challenges of climate change, energy transitions and sustainable prosperity. Given the urgency of addressing societal grand challenges by using “Big Science” to drive solutions, **failure is not an option**.