The New Applied Innovation Policy Challenges Facing NSF Engineering

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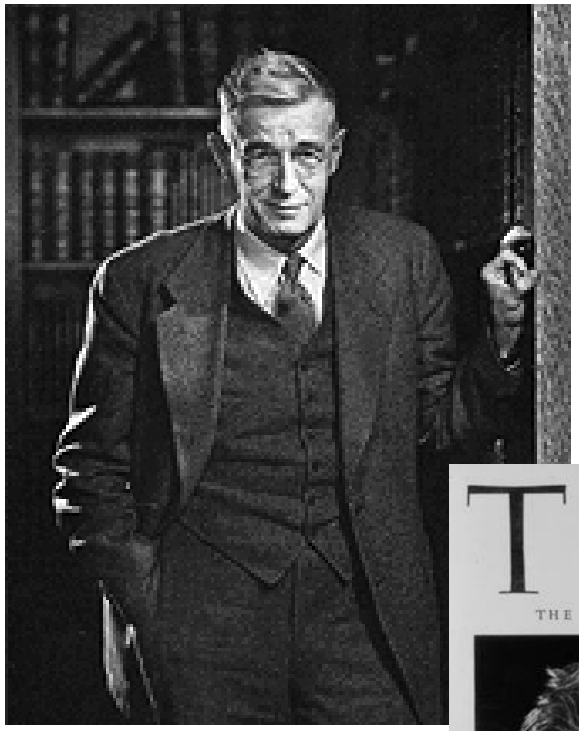
It starts with: Vannevar Bush, 1890-1974 – FDR's Science Advisor



Vannevar Bush, "*Science - The Endless Frontier*" (at nsf.gov, 1945)

- 11/17/44 – FDR writes Bush (did Bush draft it for him?)
  - What's gov't role in supporting research?
- FDR's "new frontiers of the mind"
  - Grasps Frederick Jackson Turners concept of the role of the frontier in American life
- Proposes new science frontier as next American frontier
  - Bush's paper comes out in July 1945 after FDR's death – the most influential policy paper ever written on US science organization
  - Bush is thinking through the postwar model for US science, thinking about the gov't's future role
  - An "industrial policy" model dominates WW2
  - Bush dis-agregates science away from this model

Vannevar Bush, "Science, The Endless Frontier", Con't:

- **Bush's Report Defines the Future Direction of US Science Progress:**
  - Bush announces new popular causes for US Science
  - Science is to be "part of a team" for "health, security, prosperity"
  - separates science as a separate player from other innovation actors – against integrated model for science
- Announces **4 goal areas** for science:
  - **1) "War Against Disease" Direction**
    - Bush and FDR saw huge medical gains in WW2 - antibiotics)
  - **2) National Security Direction**
  - **3) "Public Welfare" Direction**
    - Goal is "full employment" – big postwar anxiety
    - "basic research is public capital"
    - science role is to add capital, value to innovation system, not to dominate it or be integrated into it
  - **4) Nurture "Talent" Direction**
    - envisions gov't role in educating science talent

Vannevar Bush, "Science, the Endless Frontier", Con't:

- Bush has a "pipeline" theory of innovation:
  - Science with gov't backing will contribute basic research, not applied
  - Industry will apply it to practical problems
  - Gov't role is to increase "scientific capital" by supporting academic research
    - This form of research is removed form "pressure for immediate tangible results"
  - Bush's idea: remove science from the fray – protect it, put it back into the ivory tower
    - Is that a good idea?

Vannevar Bush, “Science, The Endless Frontier”, Con’t:

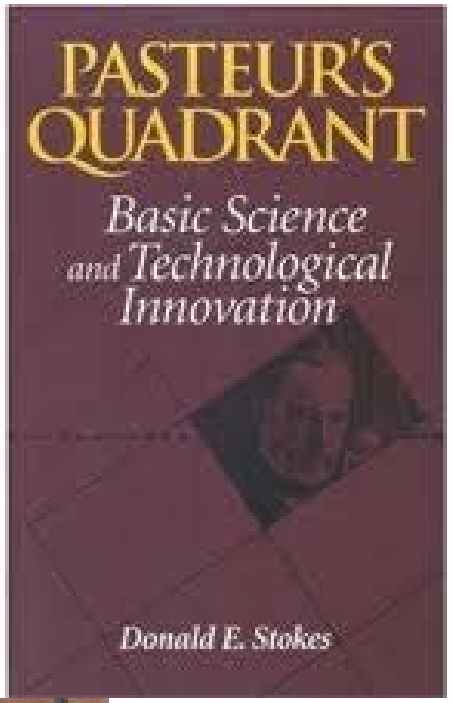
- **Bush calls for a “New Agency” to carry out the directions he proposes for US science – *One Big Tent***
  - NSF - New agency to support “basic science”
    - Research direction and control will remain in academia, with gov’t providing funding and minimal supervision
  - It’s vetoed and delayed unitl 1950
  - Meanwhile defense R&D, AEC and NIH move out ahead and separately
  - therefore there is no unified science funding agency as he envisioned – US science is fragmented because of the delay

But: President Harry Truman vetoes Bush's NSF Act

- Bush's dream of one science agency ends
- Bush wanted scientists naming scientists to lead; Truman asserted Pres. appointment power ("the buck stops here")
- Result: NSF delayed until 1950; US has decentralized science
- Cross- agency, cross-science collaborations very hard in the US system

Prof. Donald Stokes, 1928-1997

Dean of the Woodrow Wilson School at Princeton (now Princeton School of Public and Int'l Affairs); died of Leukemia shortly after finishing "Pasteur's Quadrant"



Donald E. Stokes, "Pasteur's Quadrant, Basic Science and Technological Innovation" (Brookings 1997)

- Stokes Argues Bush's Basic Research Cannon Has **Two Parts**:
- **"It Is Performed Without Thought Of Practical Ends"**
  - Designed To Persuade Country That Attempts To Constrain Free Creativity Of The Basic Scientist Would Be Inherently Self-defeating
- **"Basic Research Is The Pacemaker Of Technological Improvement"**
  - Designed To Persuade The Policy Community That Investment In Basic Science Would Yield The Technology To Solve A Broad Spectrum Of National Needs
- ***Stokes: neither is true***

Donald Stokes, Pasteur's Quadrant, Con't

- But Stokes notes: the ties between science and technology aren't linear, they are interactive
- Use-inspired science yields both basic and applied results
- Bush's effort on behalf of the science community to preserve the autonomy of publically-funded science led him to decry efforts to constrain the creativity of basic research
  - but it is eventually self-defeating because it's not the right model
- Challenges to Bush's ideology grew insistent as US needs shifted from the military to economic sphere

Stokes: The Problem, Con't

- But Stokes notes: the ties between science and technology aren't linear, they are interactive
- Use-inspired science yields both basic and applied results
- Bush belief: *understanding and use are conflicting goals*, so basic and applied research must be separated
- *"applied research drives out pure"-V.Bush*
- (So: US has had historic trouble converting its leadership in technology inventions into products – Bush made this a suspect activity)
- **Bush's segmented linear/pipeline model:**

Basic-->applied--> development--> production/operations

Stokes' PASTEUR'S QUADRANT:

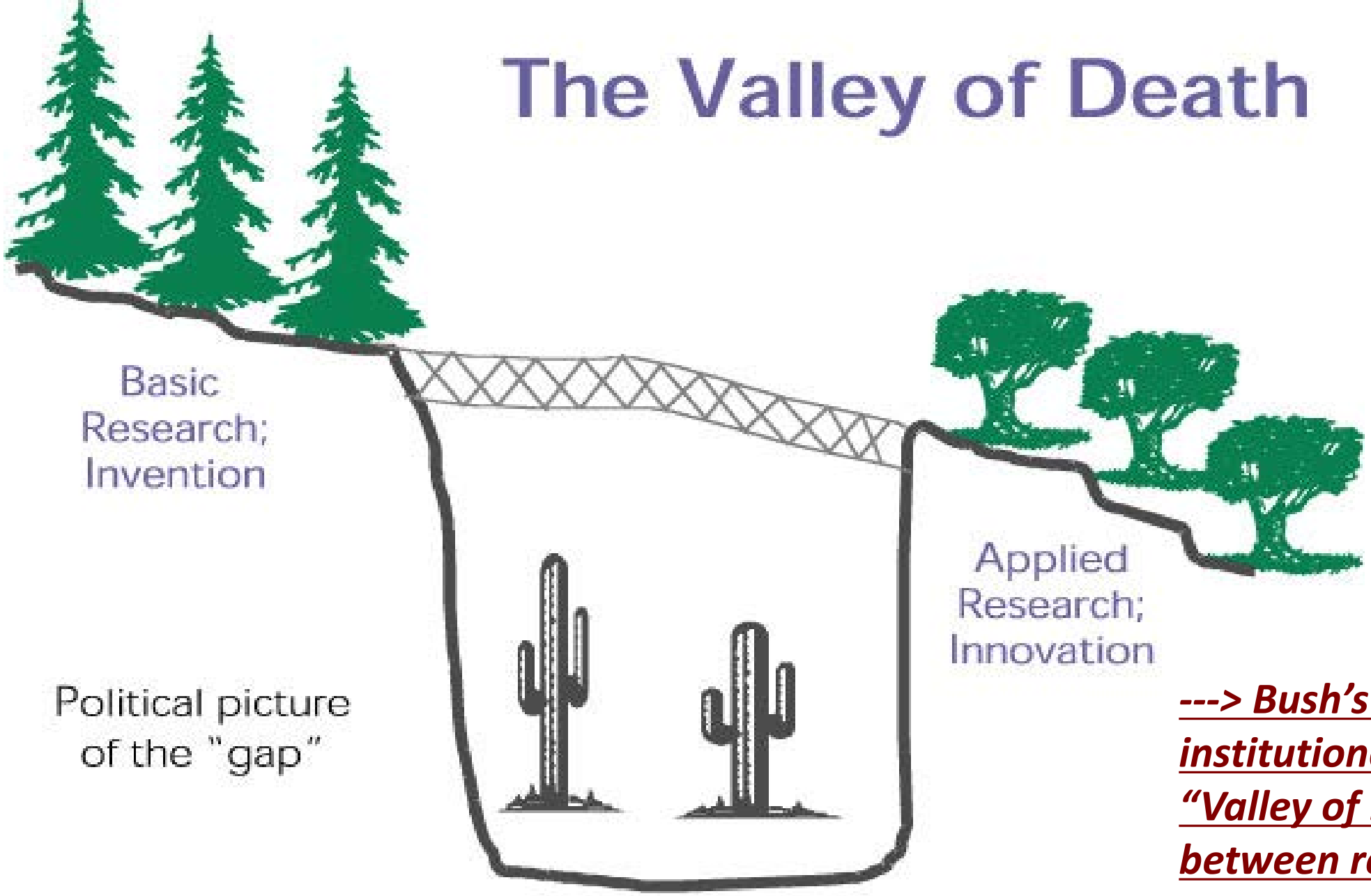
- **Consideration of Use?**

Search for fundamental under-standing	No	Yes
Yes	**Pure basic research – *Ex- Nils Bohr***	***Use inspired basic research – Ex- Louis Pasteur***
No	**Review of the particulars not the general -- *early Darwin***	**Pure applied research – *Ex-Thomas Edison***

Stokes: The Problem. Con't -

- **The deepest flaw in the V. Bush paradigm is that technology development flows one way, from science to technology**
- **BUT: there is a reverse flow – from technology to science**
- **Science is interactive – it is a whole, not segregated**
- **There is a growing amount of technology that flows from science, but the other way is strong**
- **It's a two-way street**

The Valley of Death



---> Bush's model institutionalizes the "Valley of Death" between research and later stage development

But what has evolved since the Stokes's Critique of Bush?

→ Models reaching further down the pipeline, requiring connections between R&D and implementation

- [See: W.B. Bonvillian, Encompassing the Innovation Panoply, *Issues in Science and Technology*, Winter 2022]

How far down the innovation pipeline does the Federal Government role go? …The DOD parallel universe

THE INNOVATION PIPELINE:

Research->Dev->Prototype->Demo->Testbed->Production->Market

NSF, DOE OS, NIH, etc.:

DOD:

DOD has a "Connected System"

US has had Five Periods where it has tried to better connect science and technology:

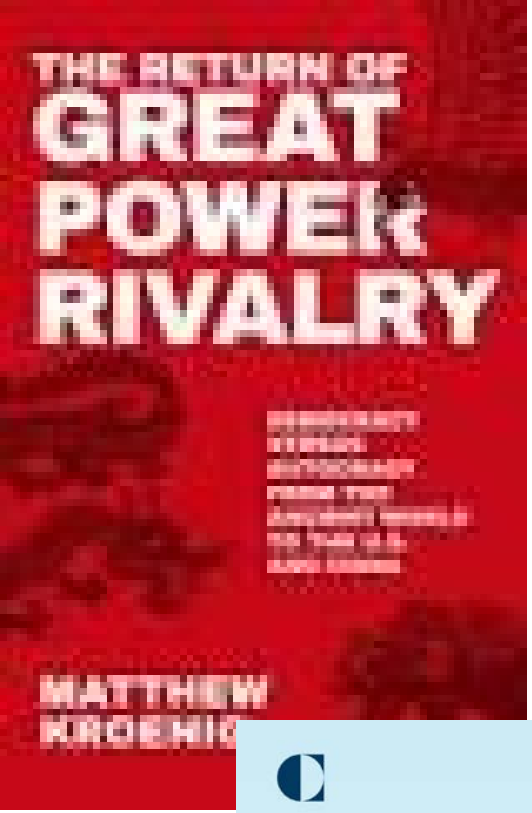
- **Period 1 – Postwar** - Moved from "connected" innovation system in WW2 to "disconnected" system with federal research role paramount
- **Period 2 – Sputnik** – DOD reconnected its innovation system – DARPA model (also NASA):
  - "right-left", use basic research capability to enable upfront" research visioning"
  - Take advantage of launching innovations into Defense innovation system- join Risk/Innovation/Connected
- **Period 3 – 80s Competitiveness**
  - Series of models to better connect R&D to "back-end" – MEP, SBIR, Bayh-Dole, ATP, Sematech, R&D Tax Credit
- **Period 4 – Energy Challenge** –
  - ARPA-E model - DARPA Plus approach – deeper into implementation
  - Expanded EERE, EFRCs, HUBs, Adv'd Mfg. Office, Tech Trans. Off., Cyclotron Rd., Loan Office
- **Period 5? – Advanced Manufacturing**
  - 16 Manufacturing Institutes – industry/univ./gov't collaboration – testbeds around adv'd mfg. technologies plus workforce ed

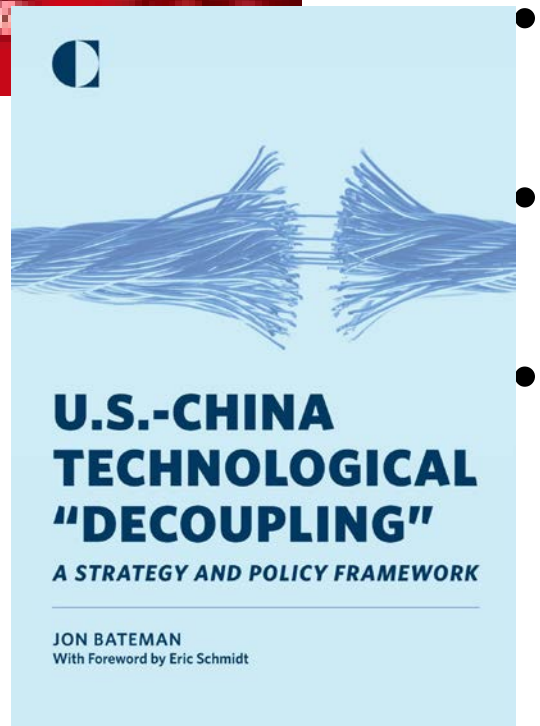
NSF has changed, too, to better connect

- NSF's Engineering Directorate created in 1981 – approx. $1 B budget
- SBIR/STTR – "America's Seed Fund" - begun at NSF, now at 11 agencies
- Engineering Research Centers – 1985, first 6 ERCs. By 2020, 75 ERCs awarded
- Major initiatives: Advanced Manufacturing, National Nanotechnology Initiative (NSF originated), National Robotics Initiative, Materials Genome Initiative
- In manufacturing: cyber-physical systems, bio-manufacturing, 2 of the 4 foundational patents on additive mfg., coordination with NIST, DOD, DOE
- Education: IUSE (Improving Undergrad STEM Ed) with NSF's EHR
- ICorps - 2012
- Merit consideration: "Broader Impacts"/"Grand Challenges"
- NSF's 10 big Ideas – a series of initiatives around research orientations – convergence, quantum, future of work, data revolution, etc.

Emerging Industrial Innovation Policy Approaches

- US has long had *industrial **economic** policy* elements – ex's: agriculture (price controls, irrigation systems, land grants, extension agents), energy (hydropower, nuclear, fossil and renewable subsidies, power regulation), health (Medicare, Medicaid) – but limited in the *industrial **innovation** policy* area
- Industrial Innovation policy –
  - Definition: focus on post R&D stages: late stage development, prototyping, testing and demonstration, production prototype, production, initial market creation
  - the US has long avoided it
  - Economists oppose it as gov't interference in markets
- But three new drivers:
    - *Technology competition with China*
    - *Climate change – new energy technologies required*
    - *Pandemic*
  - But barriers: Vannevar Bush organized US civilian science in the pipeline model for basic research only
  - Although in parallel: Defense research, alternative system, reaches all stages through market creation





The New Geopolitical Driver

- Another period where democratic governments are challenged by autocratic governments – Matt Kornig, *Return of Great Power Rivalry* (2021)
  - Reality: the Ukraine War, China' support for Russia in that war, and ongoing potential threats to Taiwan
- Dangerous situation – underscores need to reestablish US supply chains and manufacturing leadership.
- Technology leadership drives national security leadership.
- Manufacturing is the crossroads between national security and economic security and the three are interdependent.

A series of major new industrial policy initiatives

- ***Most important of all: Operation Warp Speed*** – massive intervention into vaccine development – guaranteed production contracts to industry, portfolio approach for range of vaccine technologies, technology certifications (EUAs), integration of federal officials into companies to speed development, control of distribution systems
- ***The CHIPS Act*** – restore US semiconductor leadership – US semiconductor firms falling behind – Intel behind TSMC, Samsung - so call for new US supported fabs and foundries, advanced R&D, fund for mfg. and packaging technologies, SC workforce ed - $52B billion in appropriations
- ***Infrastructure bill in 2021: Energy tech demonstration centers*** for carbon capture and sequestration, hydrogen, adv'd nuclear, critical minerals, renewables - $20 billion – new Technology Demonstration Office
- ***Assuring Domestic Supply Chains*** – June '21 WH plan, updated Feb. '22 – for pharmaceuticals and ingredients, advanced batteries, critical minerals, semiconductors – financing and supply chain rebuilding
- ***Inflation Reduction Act*** - $375B for new energy/climate challenges – tax and consumer incentives for implementation of efficient technologies

And Now: The "Endless Frontier" /"US Innovation & Competition"/"Competes"/"CHIPS & Science" Act ---

- Started by Sen's. Chuck Schumer (D-NY) and Todd Young (R-Ind.) –bipartisan cosponsors - $100 billion authorized (current & new), Administration support
- *Core Idea*: U.S. technology history is littered with technologies innovated *here* in the U.S., that did not scale-up here, and were produced *there*.
  - Flat panel displays, solar panels, lithium ion batteries, drones, etc.
  - A core goal of this bill is to get the new critical technologies into range of industry acceptance – *here*. The new technologies require de-risking to get into the scope of risk and corresponding costs so industry can absorb and implement them.
- Intense competition for critical tech leadership with China –
  - Will pass the US in gov't R&D support soon
  - Has Guidance Funds authorized for $1.2 Trillion for industrial scale up (Adler, *Amer. Affairs*);
  - $500B in industrial subsidies (CSIS report)
- Who will lead on AI, quantum, new high performance computing, robotics, biotechnology, cybersecurity, advanced materials, energy tech?

The Endless Frontier Act – Elements in the Bill:

- **New Technology Directorate at NSF**
  - NSF is our one major, broadly-focused R&D agency not tied to a specific, and narrower, mission. It does largely basic discovery-oriented science research in a range of fields
  - Legislation forms a technology-focused sub-unit within the agency – agency within the agency
  - Some argued this will create a culture clash within NSF.
  - But - long history of basic and more use-inspired/applied working in tandem, and the cultures can be complementary – DARPA works alongside the Office of Naval Research, and ARPA-E alongside the DOE's Labs and Office of Science.
  - Still, new Directorate will have to shift from NSF's basic science, peer-review culture
  - Directorate is given DARPA-like powers (personnel, contracting)

Endless Frontier Act – has *some* of the follow-on stages to research:

- To move new technology (as opposed to science discovery): series of stages, post-research – Must move through: research, development, prototype, testing, demonstration, scale-up/piloting, initial market, full production.
  - ***R&D in critical technology areas*** –later stage research as well as development to be performed at the **new Technology Directorate**.
  - ***Societal goals*** added – underperforming regions, etc.
  - ***Dropped:***
    - *Development and prototyping* – at **University Technology Centers**, and importantly, these can be consortia, including industry participants.
    - *Testing and demonstration* – **test beds** to prove and demonstrate the new technology so they can get into the risk range that industry and other kinds of capital can work with.
    - ***Scale-up*** financing provision
  - **Regional Innovation Centers** – NSF undertaking for spreading innovation capability

Other elements:

- Regional innovation Hubs
  - 10 – at Commerce EDA & NIST
  - for scaling-up toward production – preparing the regional tech infrastructure for introduction
- Workforce Education
  - Major investments in STEM education
  - Funding for Semiconductor workforce in CHIPS Act
  - But: left out the technical workforce – need ATE workforce ed program w/CCs
- Manufacturing Institutes
  - $1B for new and existing institutes – Commerce
  - Expanded Manufacturing Extension Program

Issues in the bill:

- Re: Tech Development:
  - Can a tech development effort be created within a basic science agency?
  - There is existing R&D in the tech areas covered by the bill at other agencies – need mechanism for coordination across agencies – hard in the US; Nanotech initiative?
- Re: Regional Hubs/Centers
  - Amazon-like competition, all lose? – and high performance failure rate
  - Need new geography for reviving US regions – but can that work for critical technologies?
- Re: Workforce Education
  - STEM ed is in the bill, but the technically-skilled workforce is left out
- Manufacturing Institutes
  - $1 B for new and existing institutes – but not well-connected into the bill
- Supply Chain
  - Need a financing provision - won't scale unless production sites get incentives and financing
  - Semiconductor story

Is a New Era of Industrial Policy beginning?

- Defense Dept. has always done industrial policy – but reaching into other critical areas of the economy now
- Driven by China's technology acceleration challenge *and* Climate Change demands
- Bipartisan support for some of this
- Requires completely new thinking by scientists/engineers –
  - They have to learn the new system from science through production

Industrial Policy Factors:

- *Scientists/Engineers will have to master new skills, it's not just research anymore:*
- Change agents
- Research foundations and connections
- Manufacturing foundations
- Mapping Supply Chains and gaps
- Testing and Demonstration
- Integration between agencies, industry and universities – committed firms
- Technology certification and validation
- Flexible contracting mechanisms – Def. Prod. Act, Other Trans. Authority
- Technology scale-up financing

Industrial Policy appears underway at scale and we aren't ready to implement it

- Need a "systems of innovation" verses the Vannevar Bush linear model
- Need to look at innovation in a dynamic way,
  - in terms of its components, flows, organizations, and underlying policies.
- Need to look at barriers and bottlenecks to the needed innovation flows,
  - With collaborating agencies brokering connections and solutions.
- Major scope of pending industrial policies says a scattered agency approach will not be enough
- Need scale-up financing
- Need a new infrastructure for implementation, that operates across agencies and uses a range of governmental assets

Thank you!

And best wishes for your study