



**ECONOMIC & HUMAN DIMENSIONS  
RESEARCH ASSOCIATES** ::::

GREATER PROSPERITY THROUGH RESOURCE PRODUCTIVITY



# PULLING NEW METRICS, AND PERSPECTIVES, INTO BUILDING OUR FUTURE

In discussion with colleagues from the Environmental Law Institute and others  
as we *Rethink Energy, the Economy and Governance*, November 19, 2021

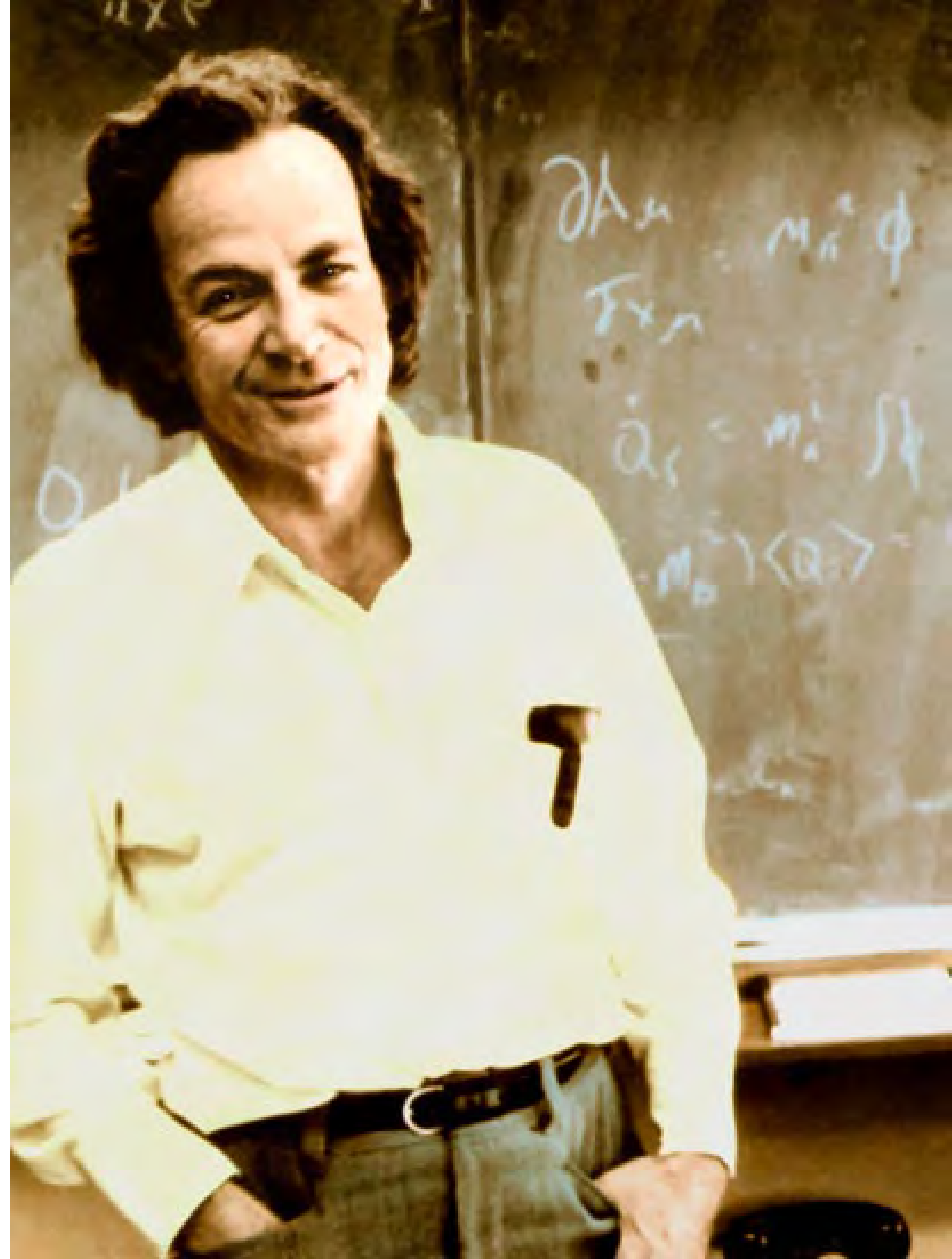
*John A. "Skip" Laitner*

*In the spirit and tradition of Nobel Laureate  
and former Caltech physicist*

# RICHARD FEYNMAN

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*Plenty of Room at the Bottom, 1959*



*But also, and very much in the spirit and tradition of Plainfield, NJ mathematical physicist. . . as well as economist*

# ROBERT U. ("BOB") AYRES



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*The Economic Growth Engine: How Energy and Work Drive Material Prosperity (with Benjamin Warr), 2009*

## But, Let's Open With. . . Key Distinctions between Energy. . . as Work, Waste and Effort

- **Energy as Work** generally refers the minimum high quality “exergy” necessary to transform matter into the delivered array of *requisite* or desired goods and services.
- **Energy as Waste** means the degradation of applied but unnecessary “exergy” (*i.e., resulting in anergy*) within the social or economic process, and which produces no social or economic value (and no longer available to do work).
- **Energy as Effort** is the combination of work and waste, or “total exergy”, as it is consumed within the social or economic processes.

# More Formally, Exploring Energy as Work

***Energy = Exergy + Anergy = Constant***

*Source: Kümmel (2011)*

***Work = Minimum Exergy Required/Task***

*Source: Ayres and Warr (2009), and Laitner (2015)*

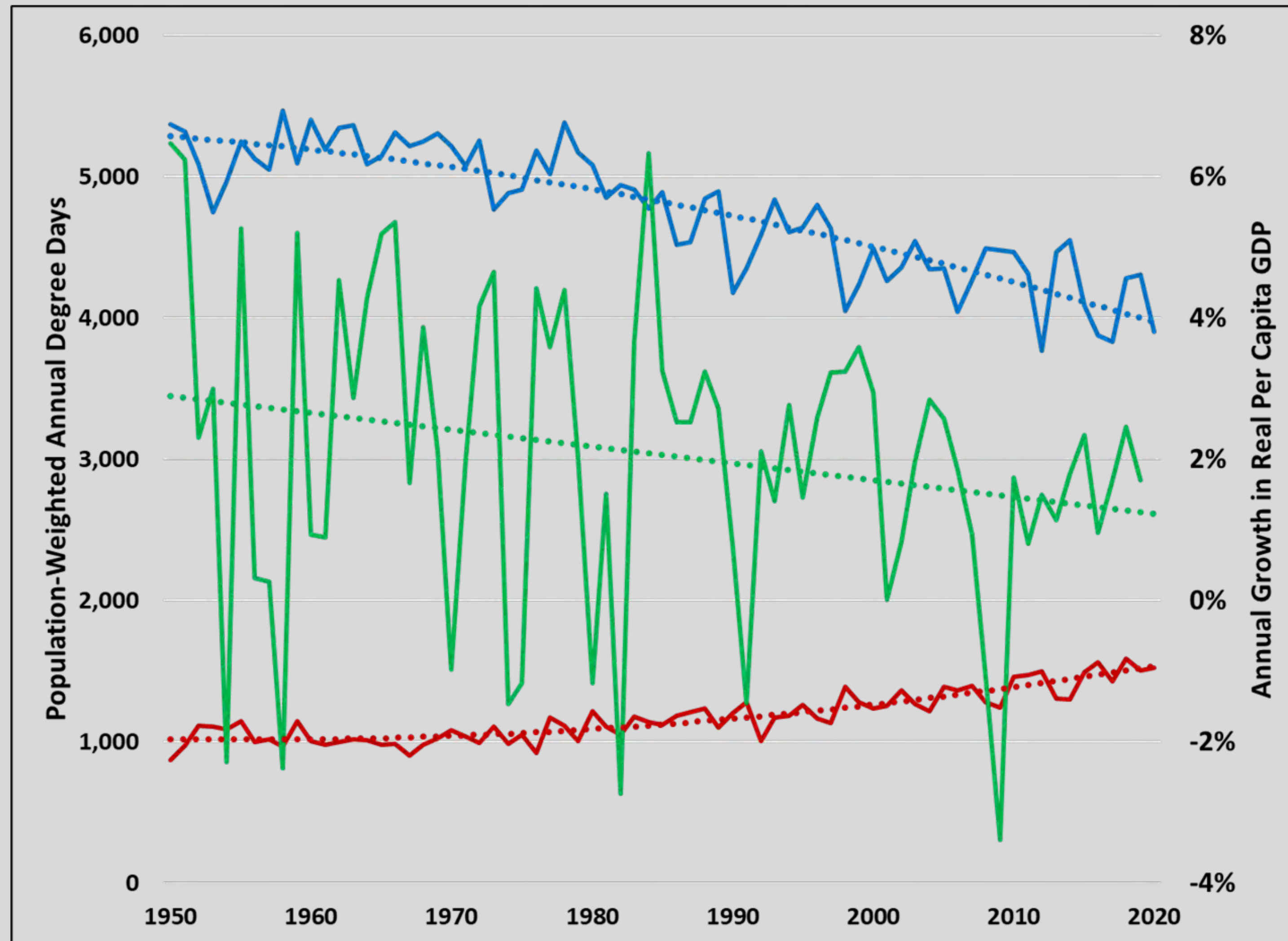
***Waste = Total Exergy Consumed - Work***

*Source: By definition*

***Total Effort = Work + Waste***

*Source: By definition*

# Trends in Heating/Cooling Degree Days and Per Capita GDP 1950-2020 – Both Driven by Energy and Resource Inefficiencies



Source: John A. "Skip" Laitner using data from the U.S. Energy Information Administration, November 2021.



**Yet, there is hope...**

**14,573 mpg**



*Student team from Duke University, and their vehicle named Maxwell (2018)*



*And yet we're happy with a Tesla 3 with a Fuel Economy of 141 MPGe?*



*If We Take a Tesla 3 at a Stated Fuel Economy of 141 MPGe,  
But Then Incorporate Other Key Life-Cycle Variables – Such as  
Vehicle Miles Driven and Source of Electricity Generation*

		MPGe Given:	
		100% Clean Electricity Production	Current Electricity Generation Profile
Lifetime Miles of Vehicle	150,000	92.3	41.6
	300,000	111.4	45.0
	500,000	121.4	46.6

THE BRIEF ROADMAP AHEAD...





A HARD DECADE OR A BAD CENTURY?



THIS THING CALLED  
ENERGY PRODUCTIVITY



SURVIVAL OF THE FRIENDLIEST



## UNDERSCORING THE NEED FOR

.....  
A better narrative, dialogue and interactions  
that stimulate:  
.....

- ▶ Imagination
- ▶ Trust
- ▶ A common understanding  
of the ***energy and  
resource imperatives***
- ▶ ***And a willingness to act  
today and tomorrow!***



WHAT CONSTITUTES  
GREATER ENERGY  
PRODUCTIVITY?



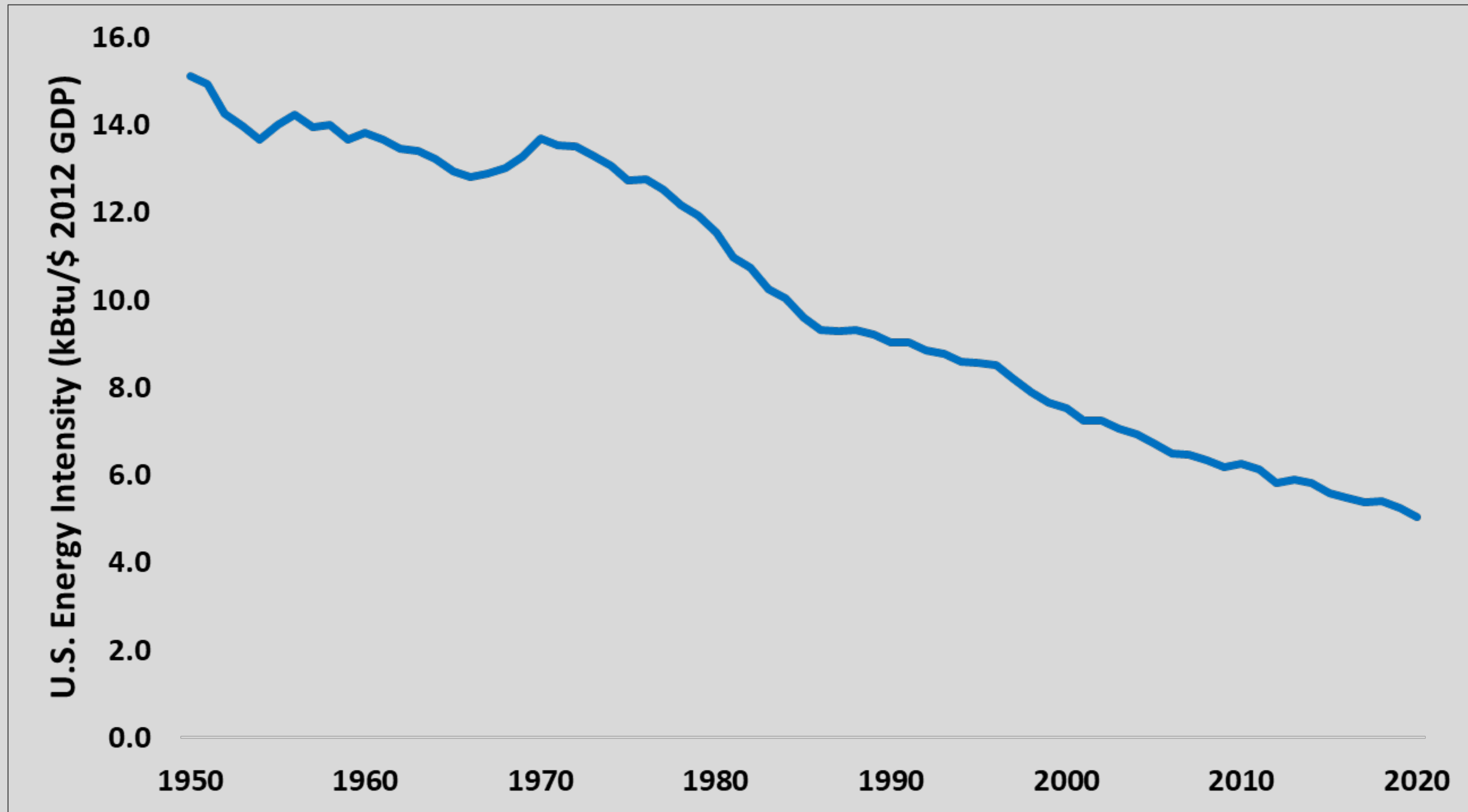


## **GREATER ENERGY PRODUCTIVITY:**

**Rather than focus merely on new energy supply, we highlight three critical elements for a robust economy:**

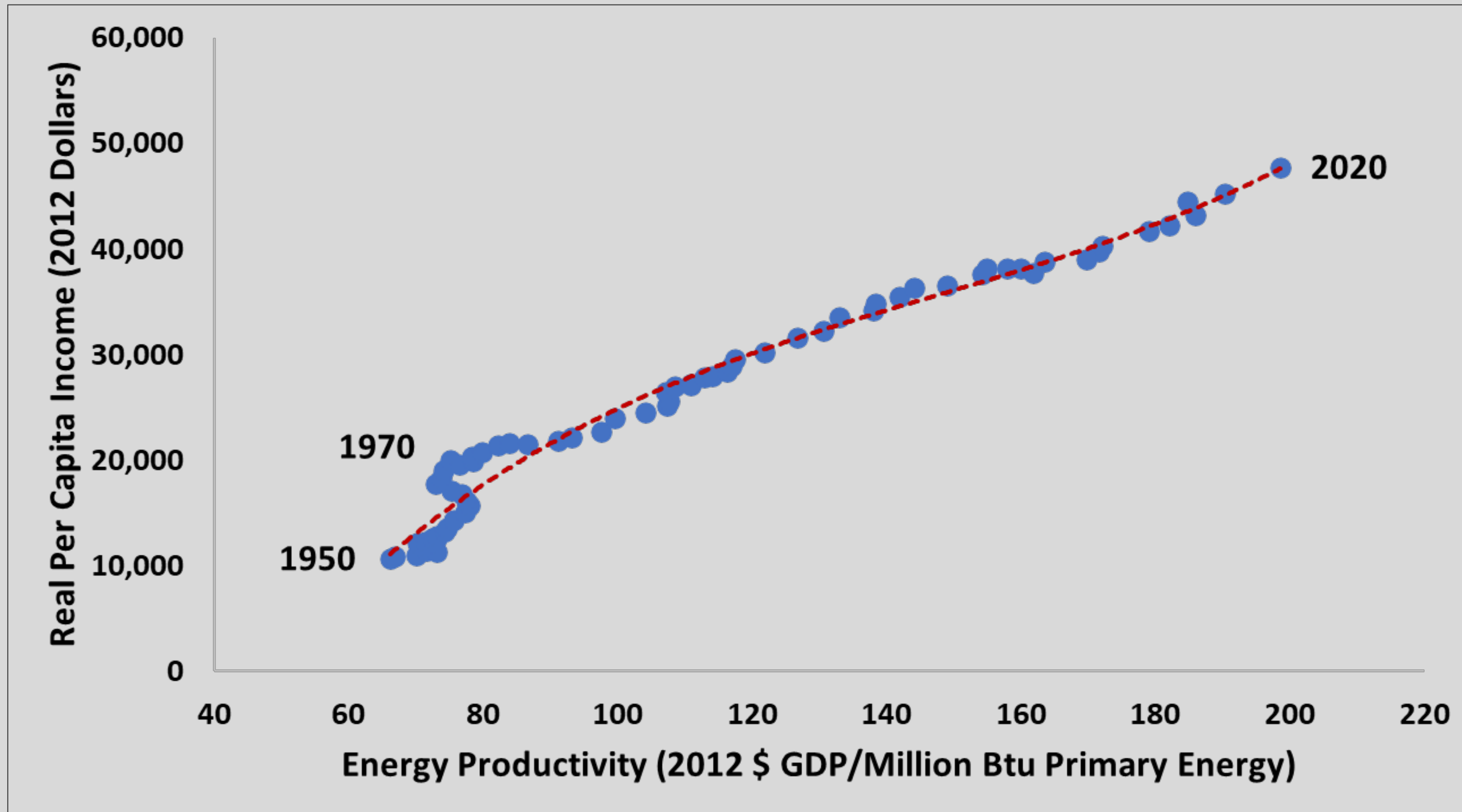
- ▶ Yes, end-use efficiency;**
- ▶ But also moving away from combustion technologies through accelerated deployment of renewables; and**
- ▶ Finally, the more productive use of capital, materials, water and food.**

# ***Rather than Focus on the Conventional Idea of Lower U.S. Energy Intensity over Time (1950-2050)***



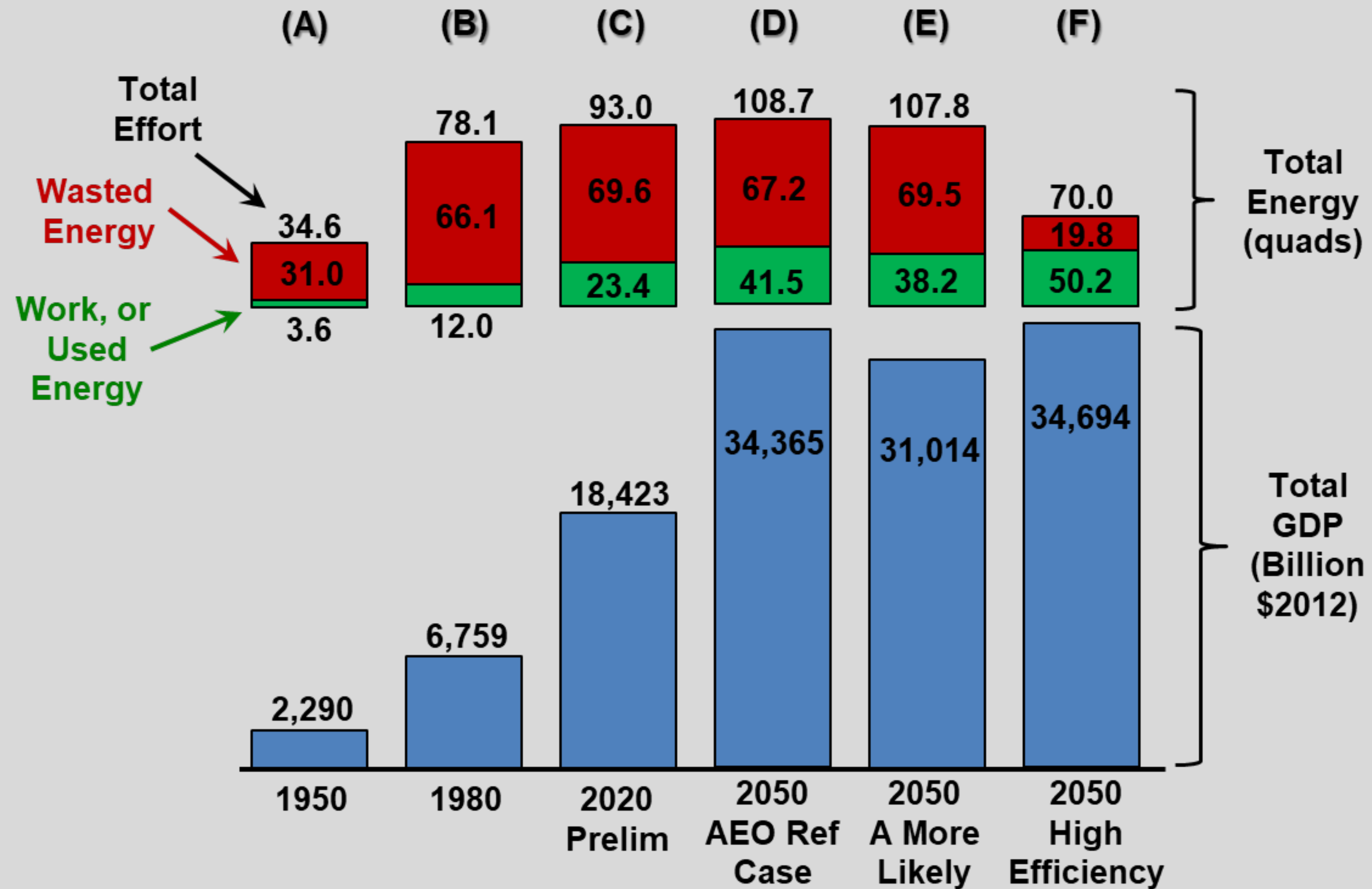
Source: Calculations by John A. "Skip" Laitner using US EIA-BEA data, November 2021.

# *Examine the Connection Between U.S. Energy Productivity and Per Capita Income (1950-2020)*



Source: Calculations by John A. "Skip" Laitner using US EIA-BEA data, November 2021.

# And . . . Also Explore Total Energy as Effort, Waste, and Work Affecting Overall GDP



\*Adapted from author calculations, and various EIA sources including, *The AEO Energy Outlook 2021*, and presented for purposes of illustration only; not as actual long-term energy and GDP projections. . .

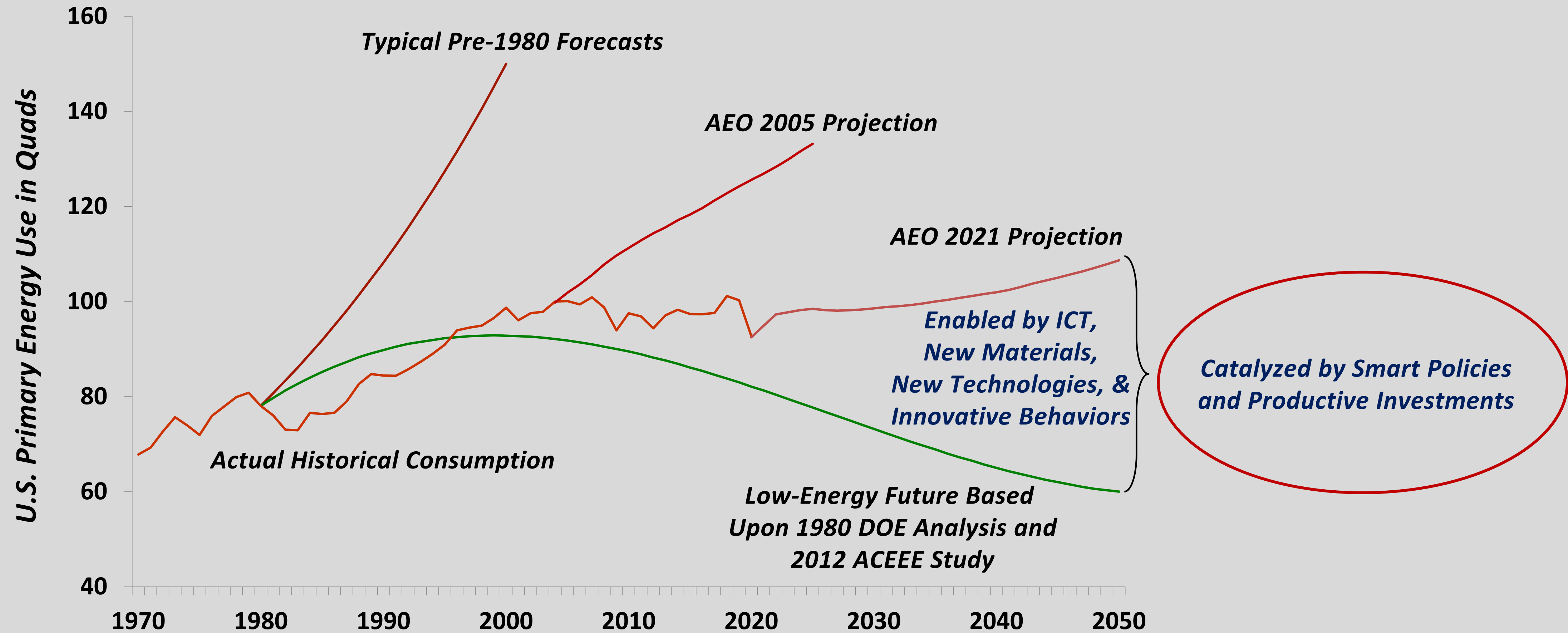
## ***And Rethinking the Implied Rebound. . . Versus. . . Total Work Required and GDP Impacts***

- On the previous chart, comparing the “Preliminary 2020” in Column C with the 2050 “high efficiency” outcomes in Column F, for example, we see the following impacts:
  - “Work Energy” Rebound =  $[(50.2 / 23.4) - 1] * 100\% = \text{up } 114.3\%$
  - Total “Effort” Needed =  $[(70.0 / 93.0) - 1] * 100\% = \text{down } 24.8\%$
  - “Wasted Energy” =  $[(19.8 / 69.6) - 1] * 100\% = \text{down } 71.6\%$
  - Total GDP Impacts =  $[(34,694 / 18,423) - 1] * 100\% = \text{up } 88.3\%$
- With these anticipated kinds of results, let’s recall the admonition of William Baumol and his colleagues: “For real economic miracles one must look to productivity growth.” And in this case, productivity growth tied to tripling the existing levels of energy productivity.

HOW BIG?

MIGHT WE REALLY GO...

# ***Key Insight: The Energy Productivity Resource Is Larger than Generally Understood or Believed***



Sources: Laitner November 2021 based on DOE 1980 Policy Analysis, AER 2021, ACEEE 2012, AEO 2005, AEO 2021

Conventional assumptions  
about the efficiency potential

**MORE  
BY WASTE  
THAN  
INGENUITY?**

**...an anemic ~16-19% Global energy (in)efficiency**

Source: Adapted from Laitner, *Smart Policies and Programs as Critical Drivers*.

Exploring the full energy  
productivity/energy  
harvesting potential:  
~100 or more billion  
barrels of oil equivalent  
for the U.S. Economy  
through the year 2050.

Enough to reduce total  
U.S. energy demand by  
~40% or more!

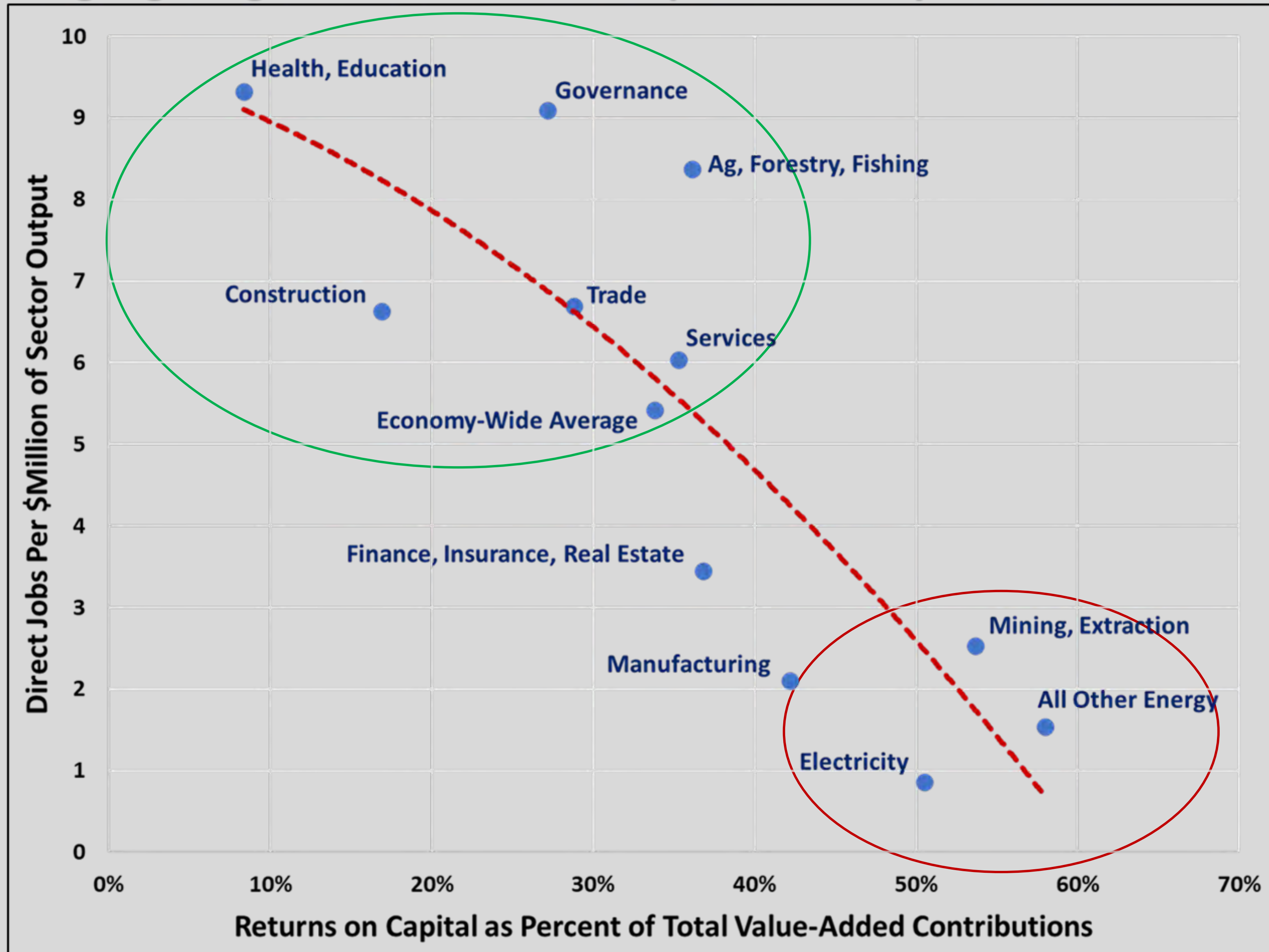
With the prospect for a  
more robust, a more  
resilient and a more  
sustainable economy. . .



AND WHAT ABOUT JOBS?

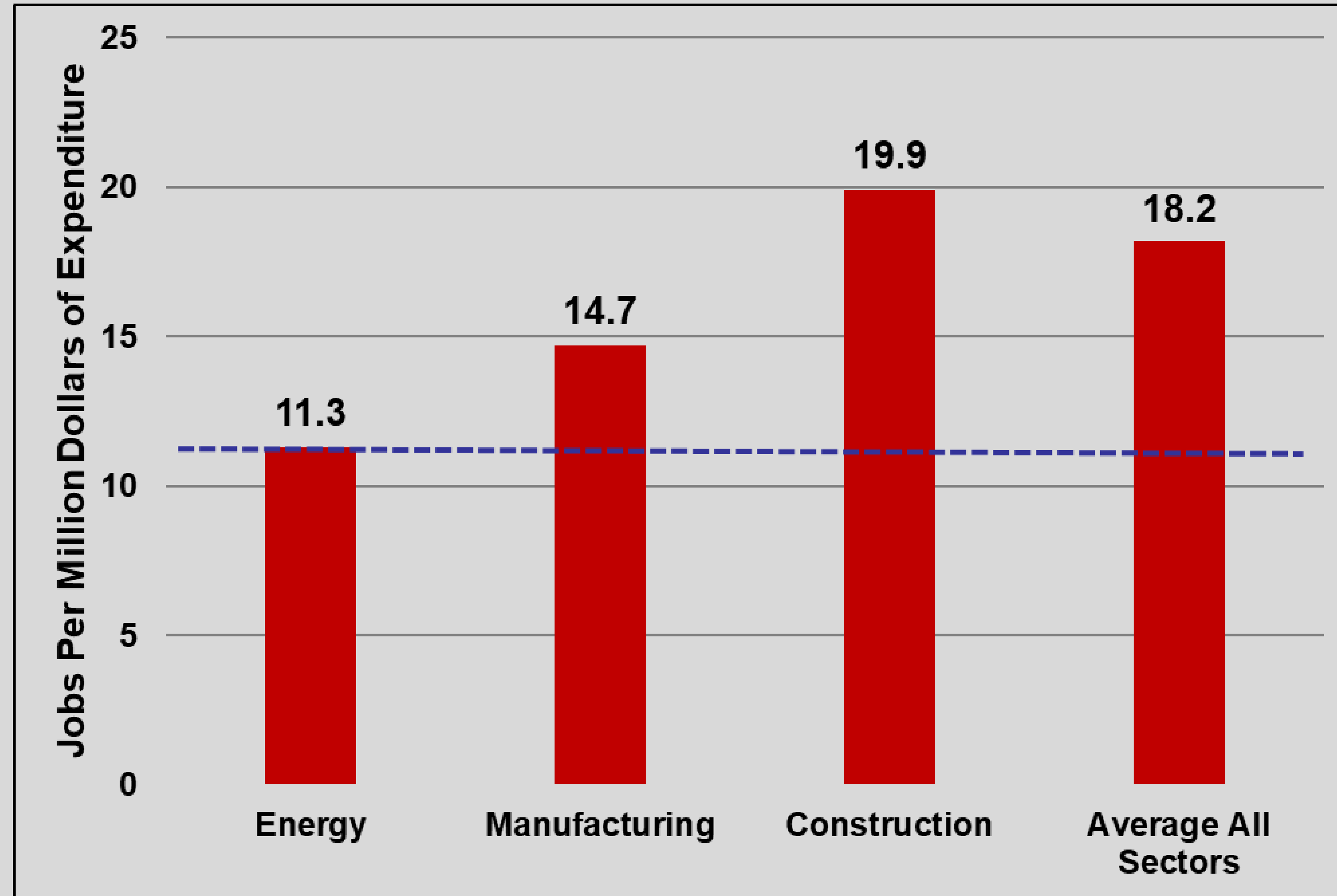


# Highlighting the Link Between Capital Intensity and Job Creation



Source: Author calculations based on US 2018 data from IMPLAN (October 2020).

# Total Jobs for Key Sectors of the U.S. Economy

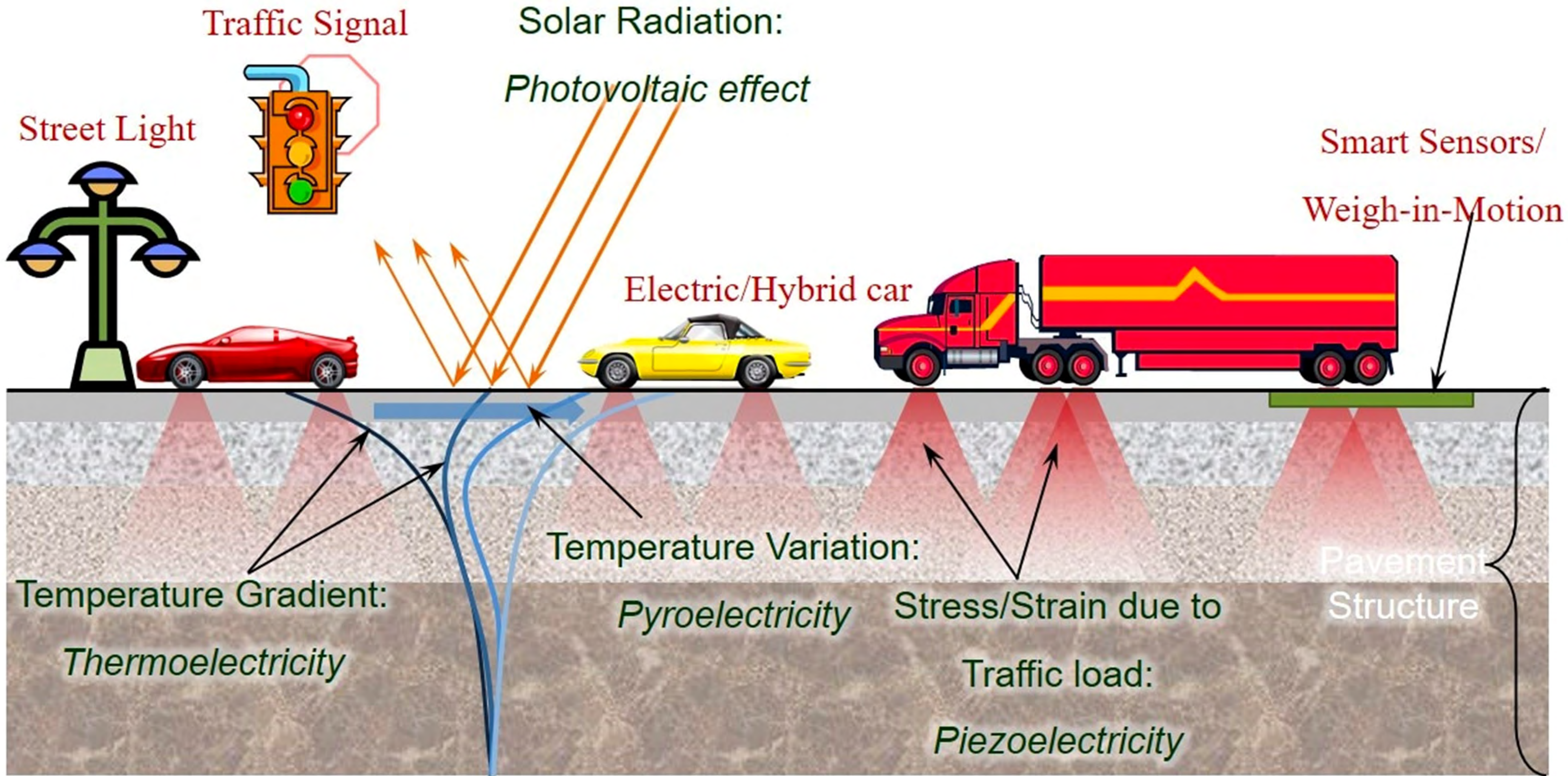


Source: John A. "Skip" Laitner, using IMPLAN 2019 Data for the United States, Jan 2021.

**AND WHAT IF WE ADD THIS THING  
CALLED ENERGY HARVESTING TO THE MIX?**



# Available Sources of Energy on Pavements and Use of Harvested Energy





**PIEZOELECTRIC DANCE FLOORS**



**ENERGY HARVESTING ELECTRONICS & TEXTILES**



**AGRIVOLTAICS**





**FLOATOVOLTAICS**

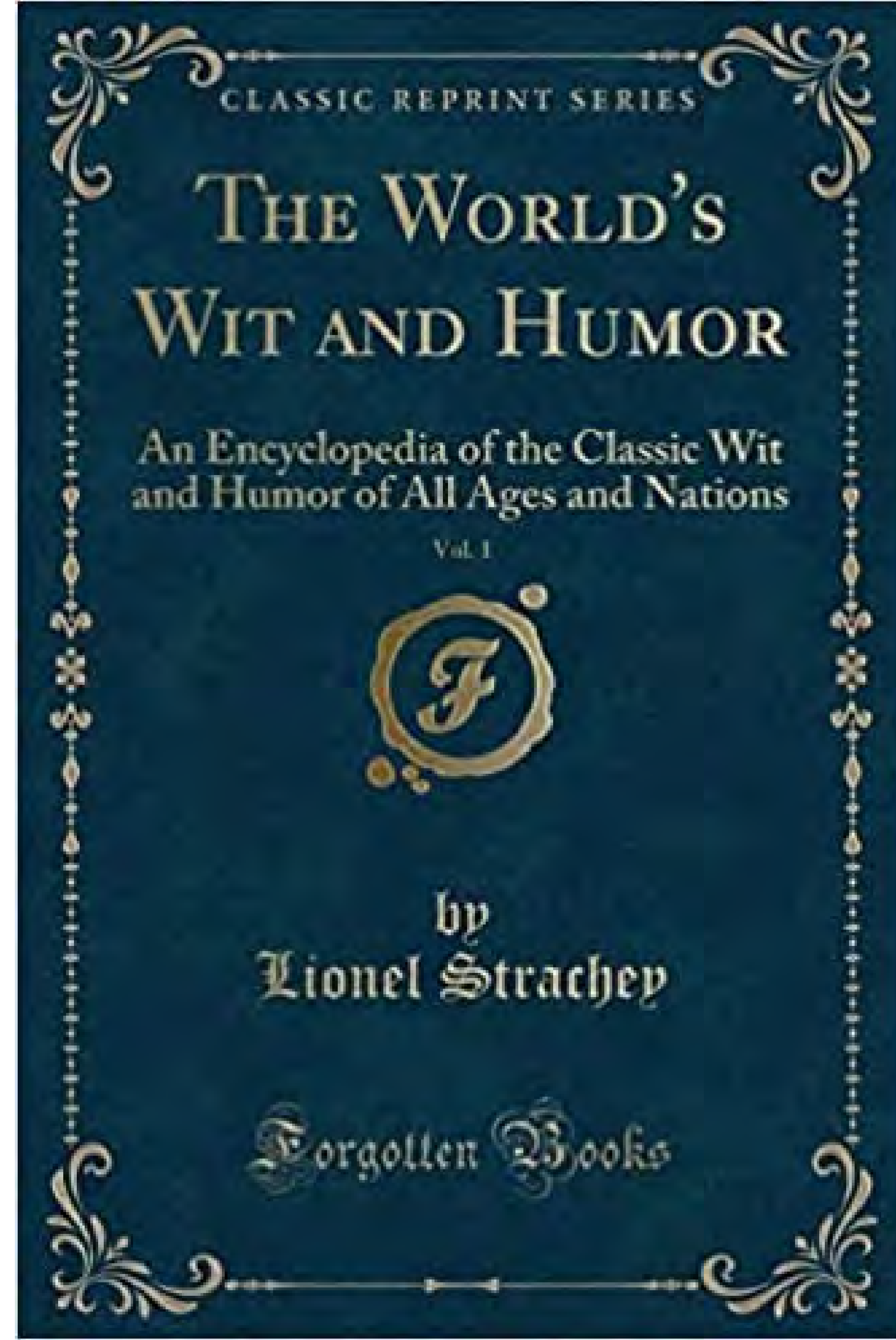
**AND PERHAPS OUR BIGGEST RESOURCE?**



**“Americans guess because they  
are in too great a hurry to  
think.”**

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*– Lionel Strachey*



**How 'moonshot' thinking  
could save the world.**

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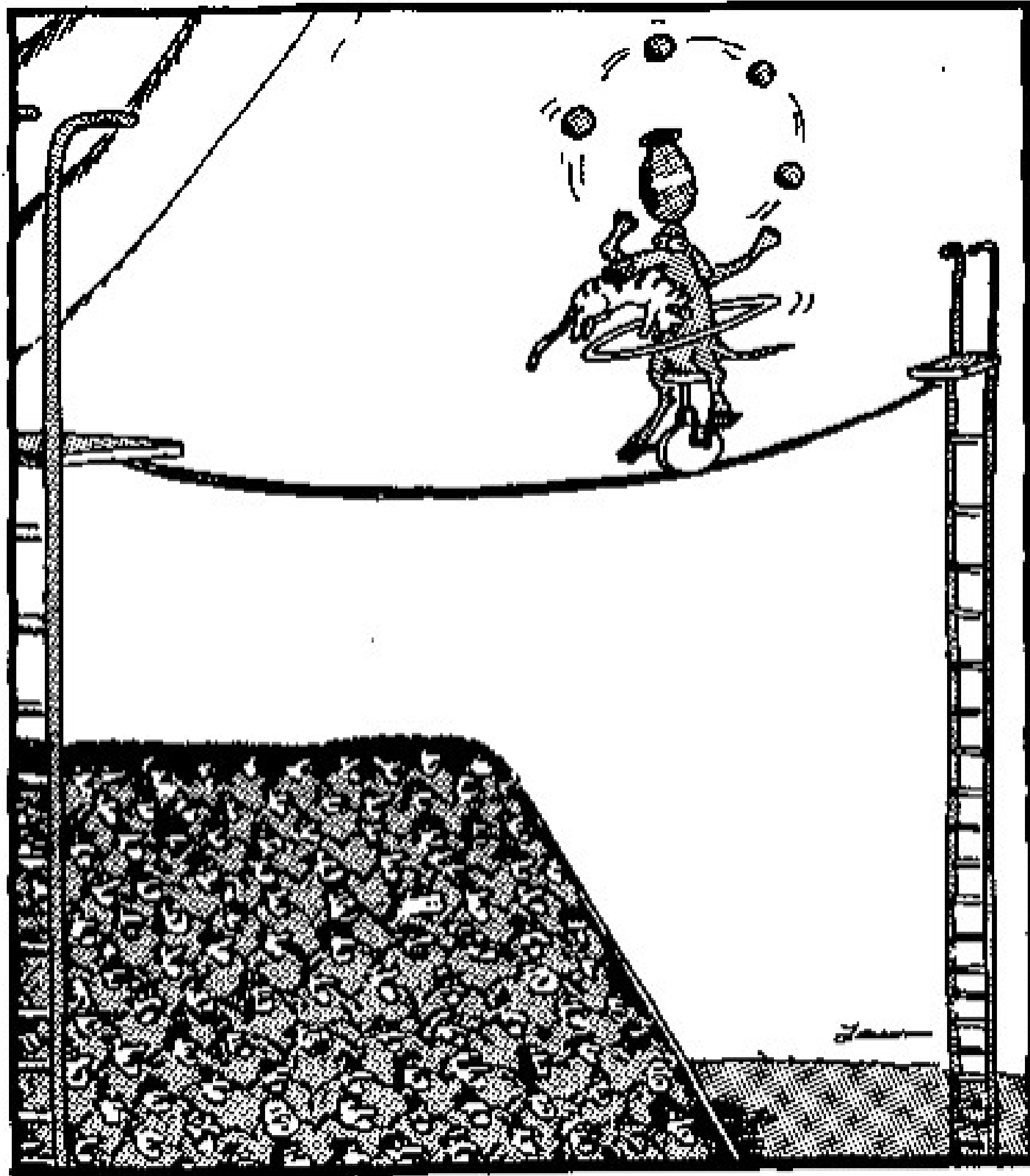
*– Mariana Mazzucato*



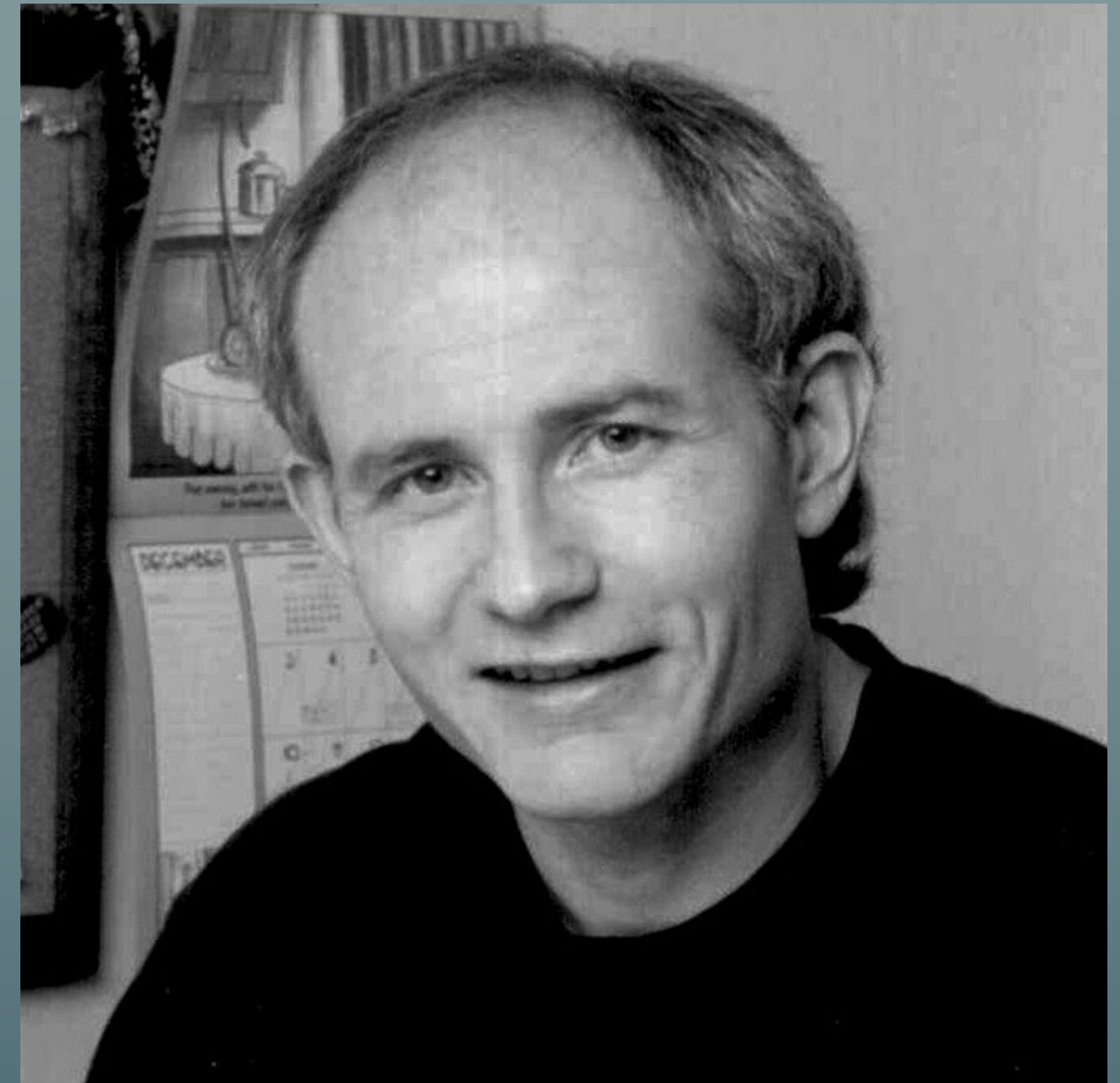


**“Thinking is the hardest work there is which is the probable reason why so few engage in it.”**

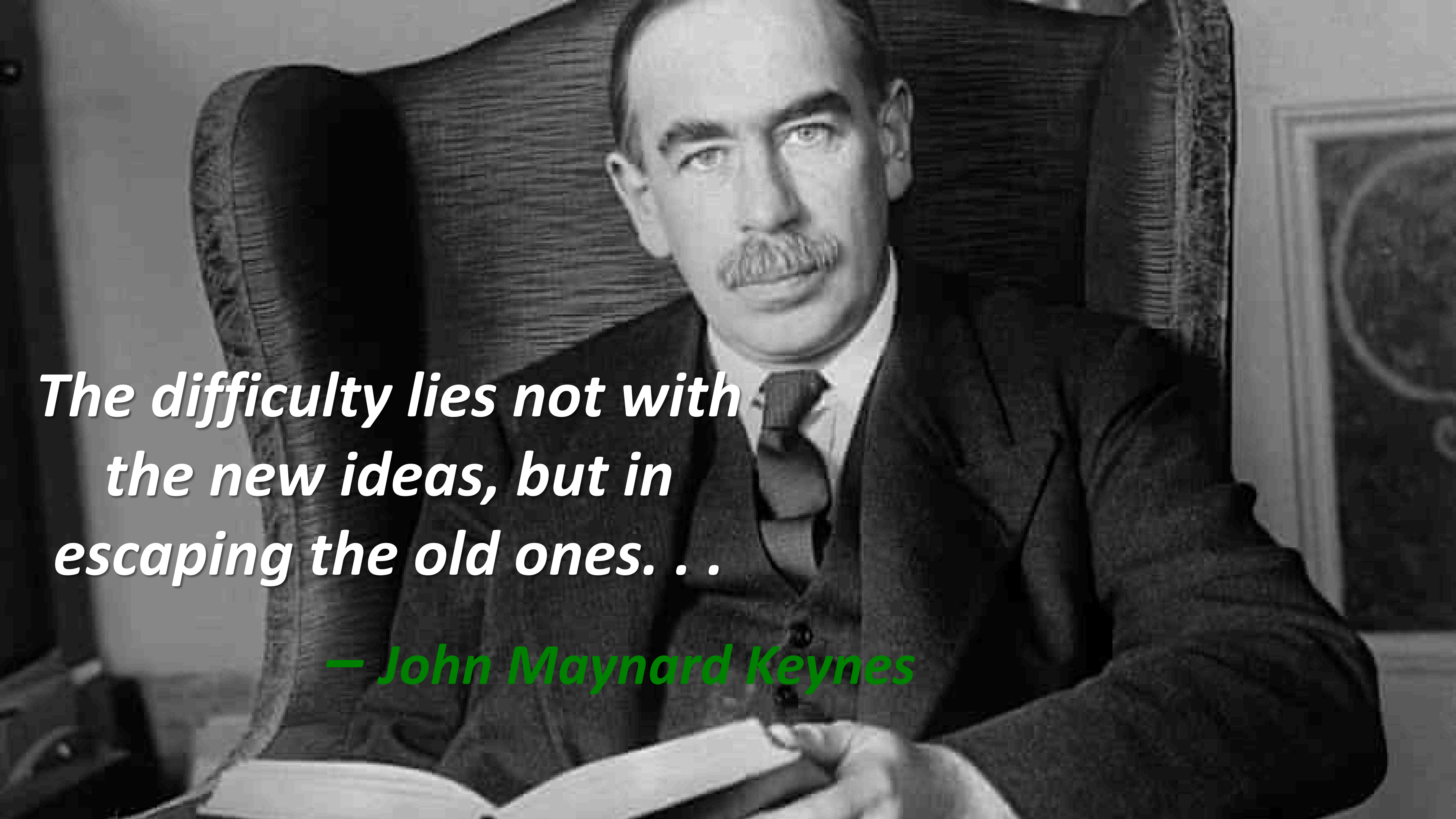
*– Henry Ford*



High above the hushed crowd, Rex tried to remain focused. Still, he couldn't shake one nagging thought: He was an old dog and this was a new trick.



*Perhaps a last word from, not my favorite physicist, but my favorite American Philosopher, Gary Larson. . .*

A black and white photograph of John Maynard Keynes. He is seated in a high-backed, upholstered chair, looking directly at the camera with a serious expression. He has a prominent mustache and is wearing a dark suit jacket over a vest and a white shirt with a dark tie. His hands are resting on an open book or document on his lap, and he appears to be holding a pen. The background is slightly out of focus, showing a wall with a framed picture or portrait.

*The difficulty lies not with  
the new ideas, but in  
escaping the old ones. . .*

*— John Maynard Keynes*

THE DIFFICULTY  
IS TO ESCAPE  
THE OLD  
IDEAS



**NOW LET'S MAKE IT HAPPEN!**