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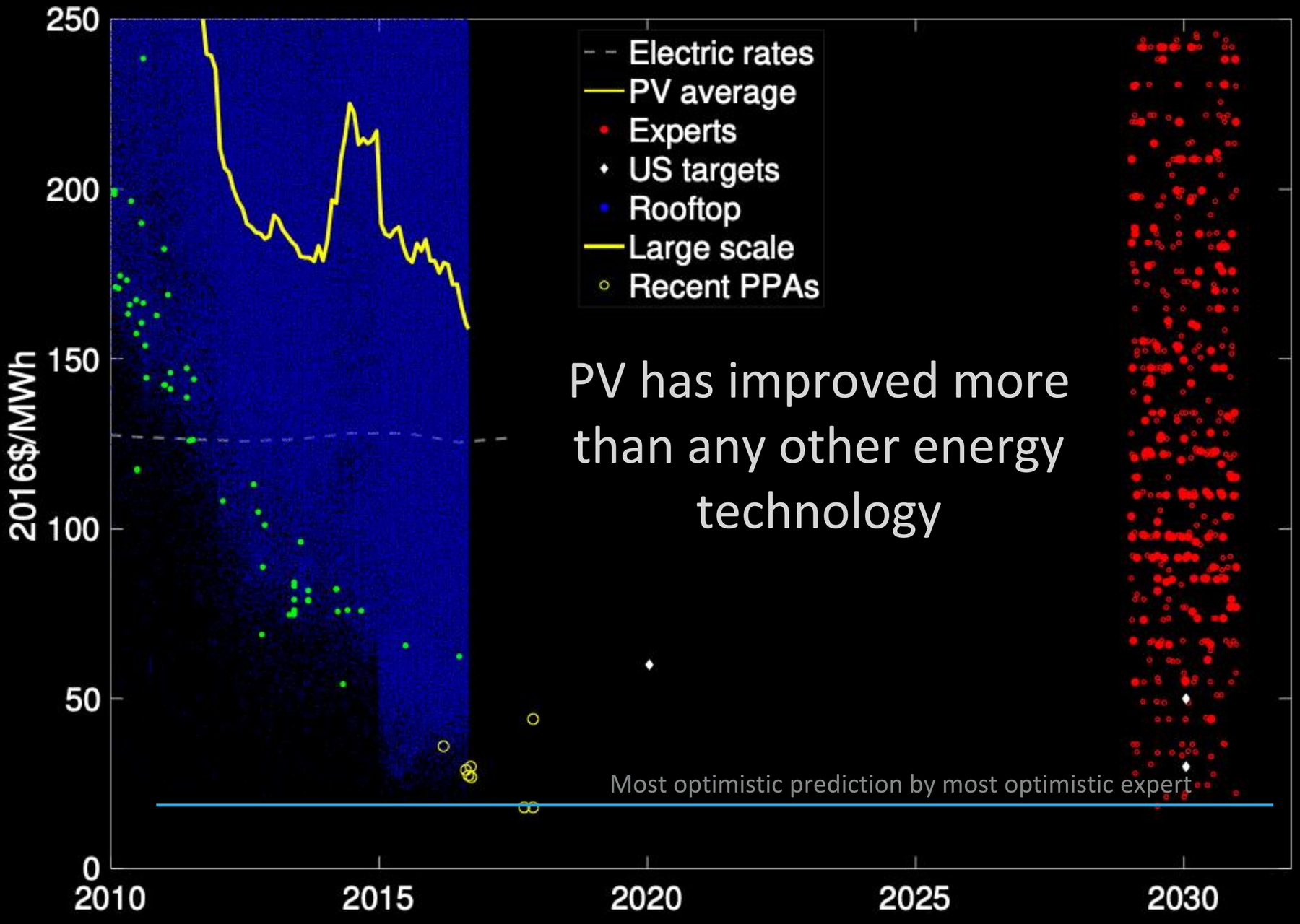
HOW SOLAR ENERGY BECAME CHEAP

A MODEL FOR LOW-CARBON INNOVATION

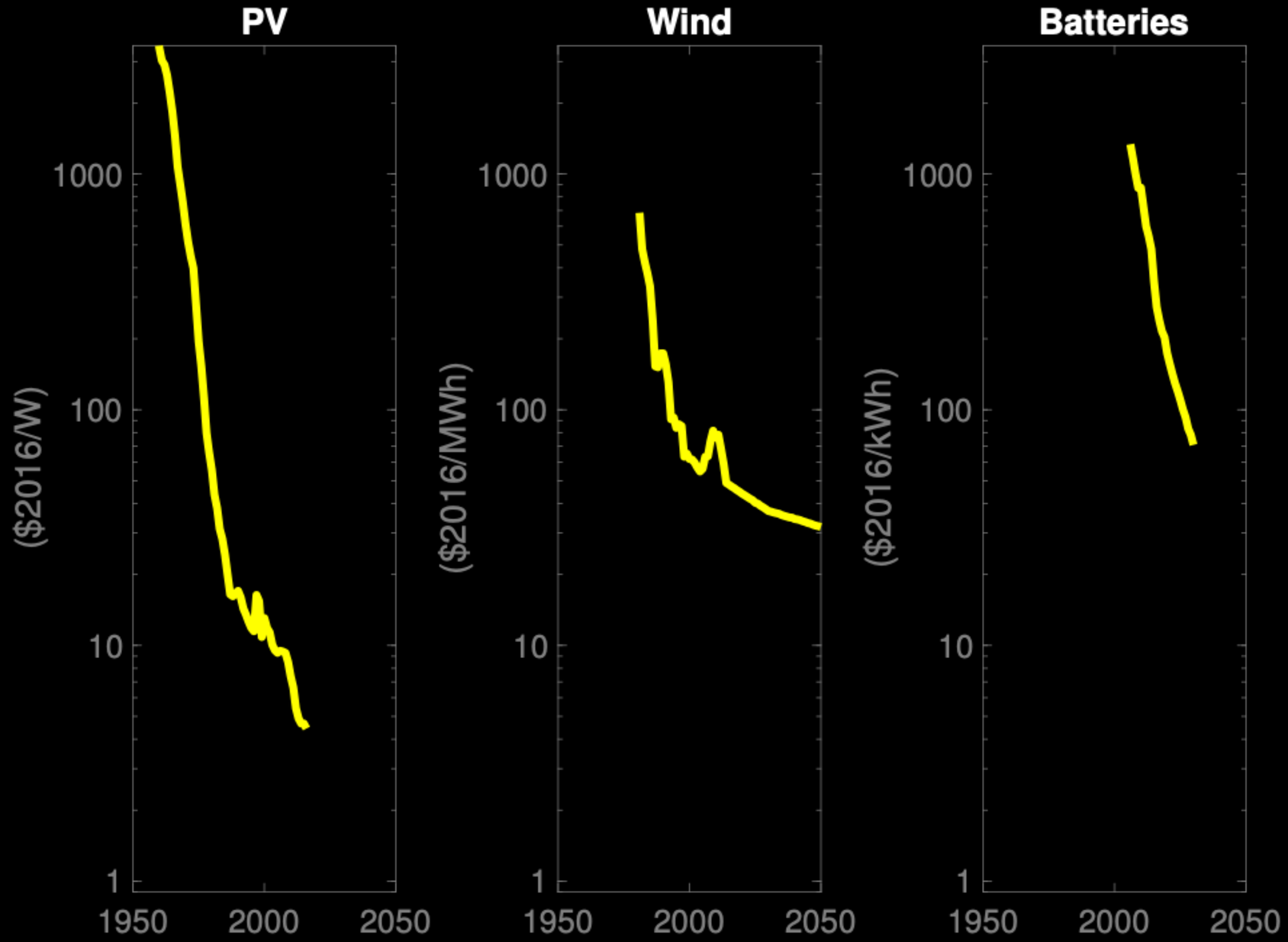
Gregory F. Nemet

earthscan from Routledge

PV IS NOW CHEAP…BEYOND EXPECTATIONS



OTHER TECHNOLOGIES TOO



RESEARCH QUESTIONS

1. How did solar become cheap?
2. Why did it take so long?
3. How can it be a model?

ANDREW CARNEGIE **FELLOWS** PROGRAM

This study was made possible by a grant from Carnegie Corporation of New York. The statements made and views expressed are solely the responsibility of the author.

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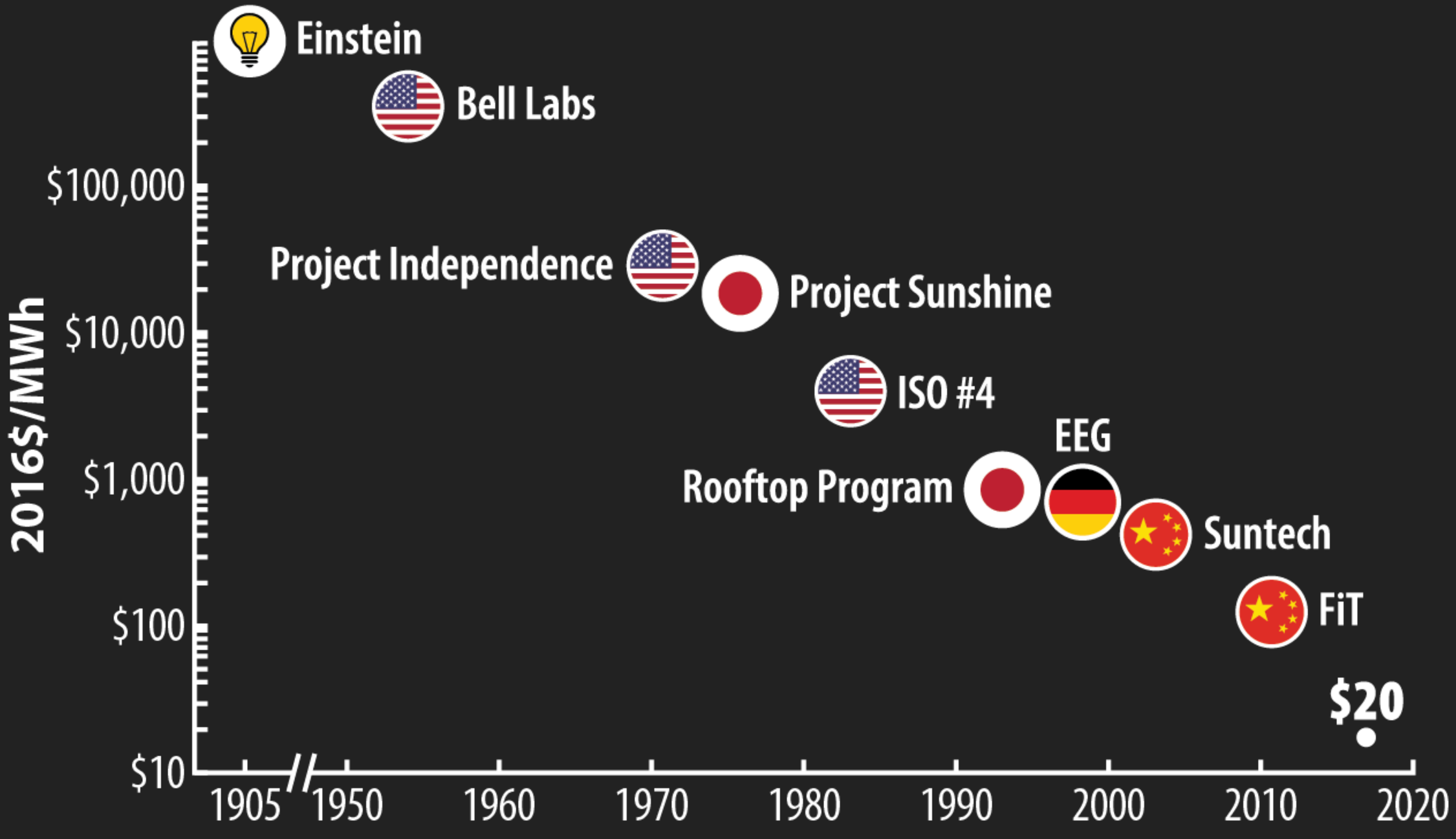
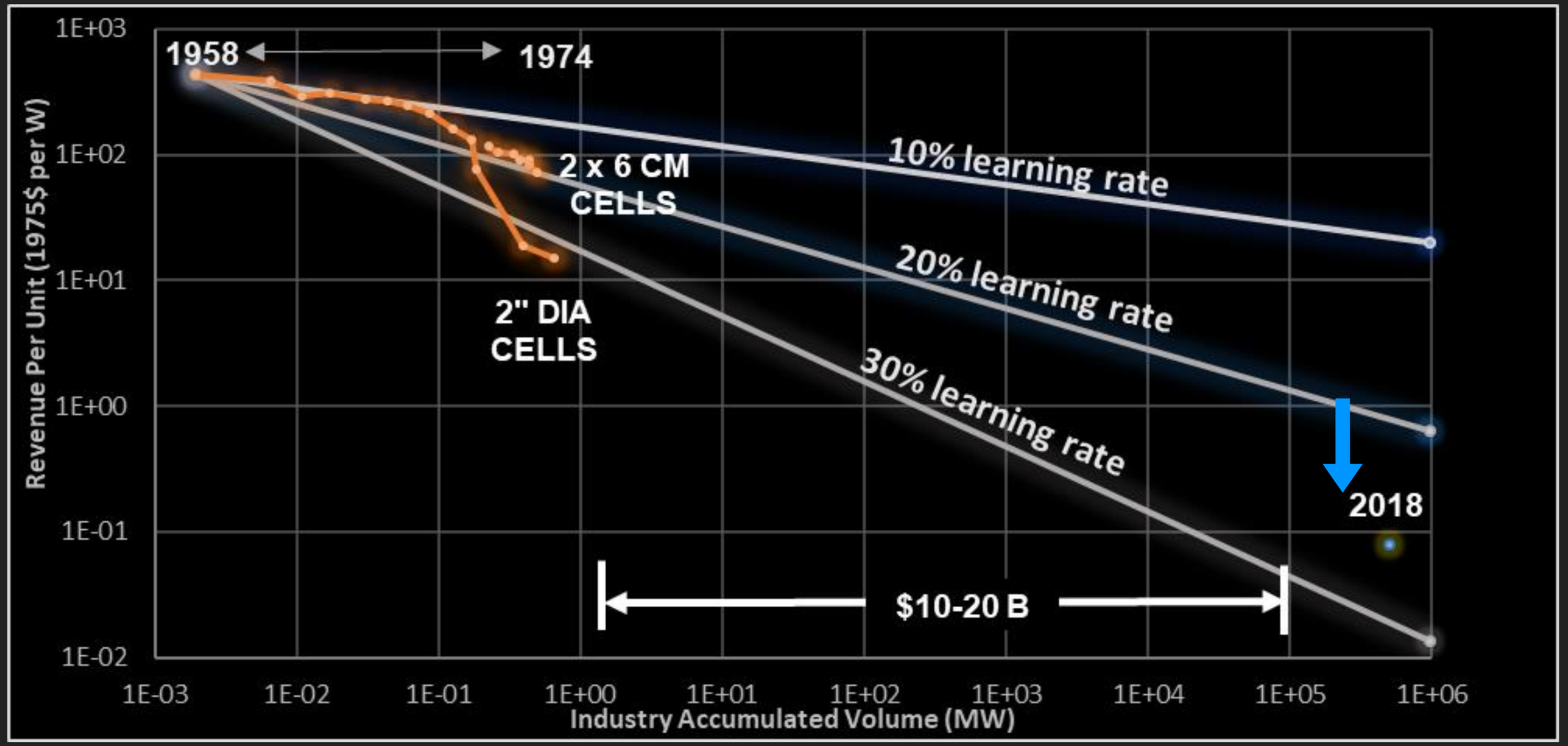
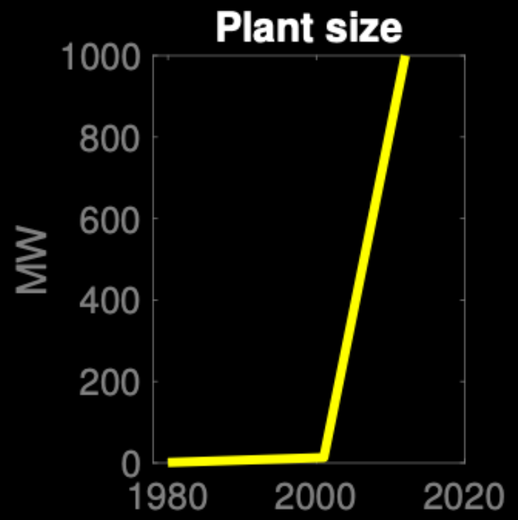
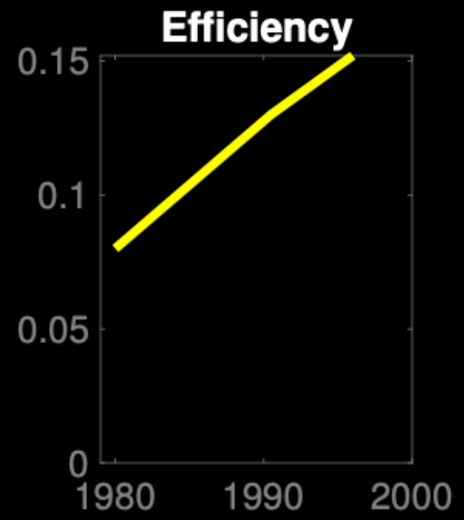

Einstein
Bell Labs
Project Independence
Project Sunshine
ISO #4
EEG
Rooftop Program
Suntech
FiT
$20
2016$/MWh
$100,000
$10,000
$1,000
$100
$10
1905
1950
1960
1970
1980
1990
2000
2010
2020

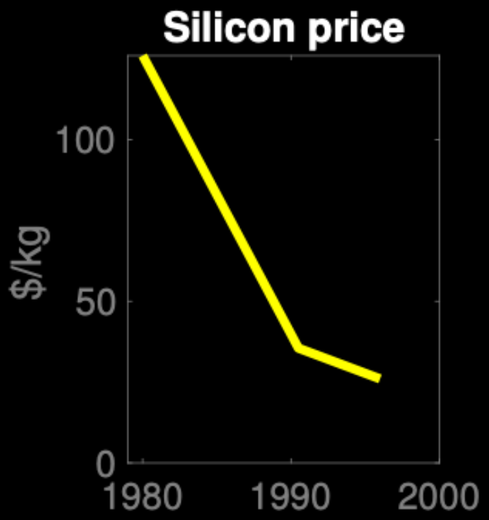
LEARNING CURVE FROM 1975

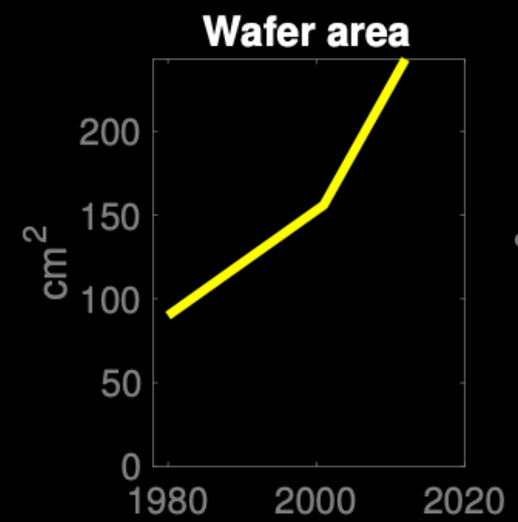


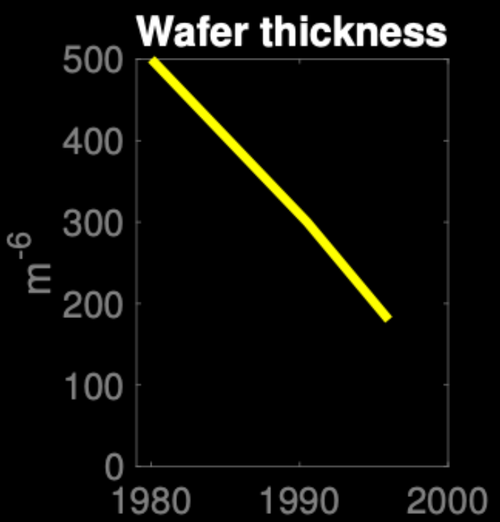
IMPROVEMENTS IN PV MANUFACTURING

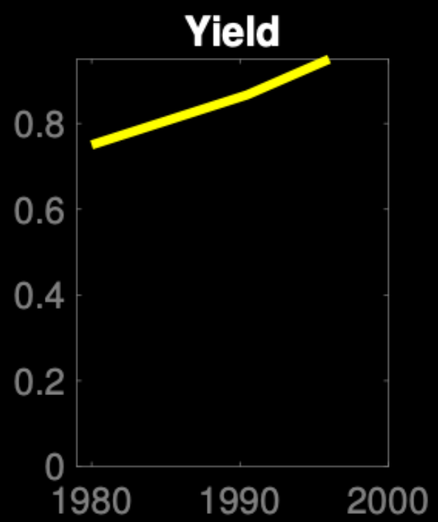




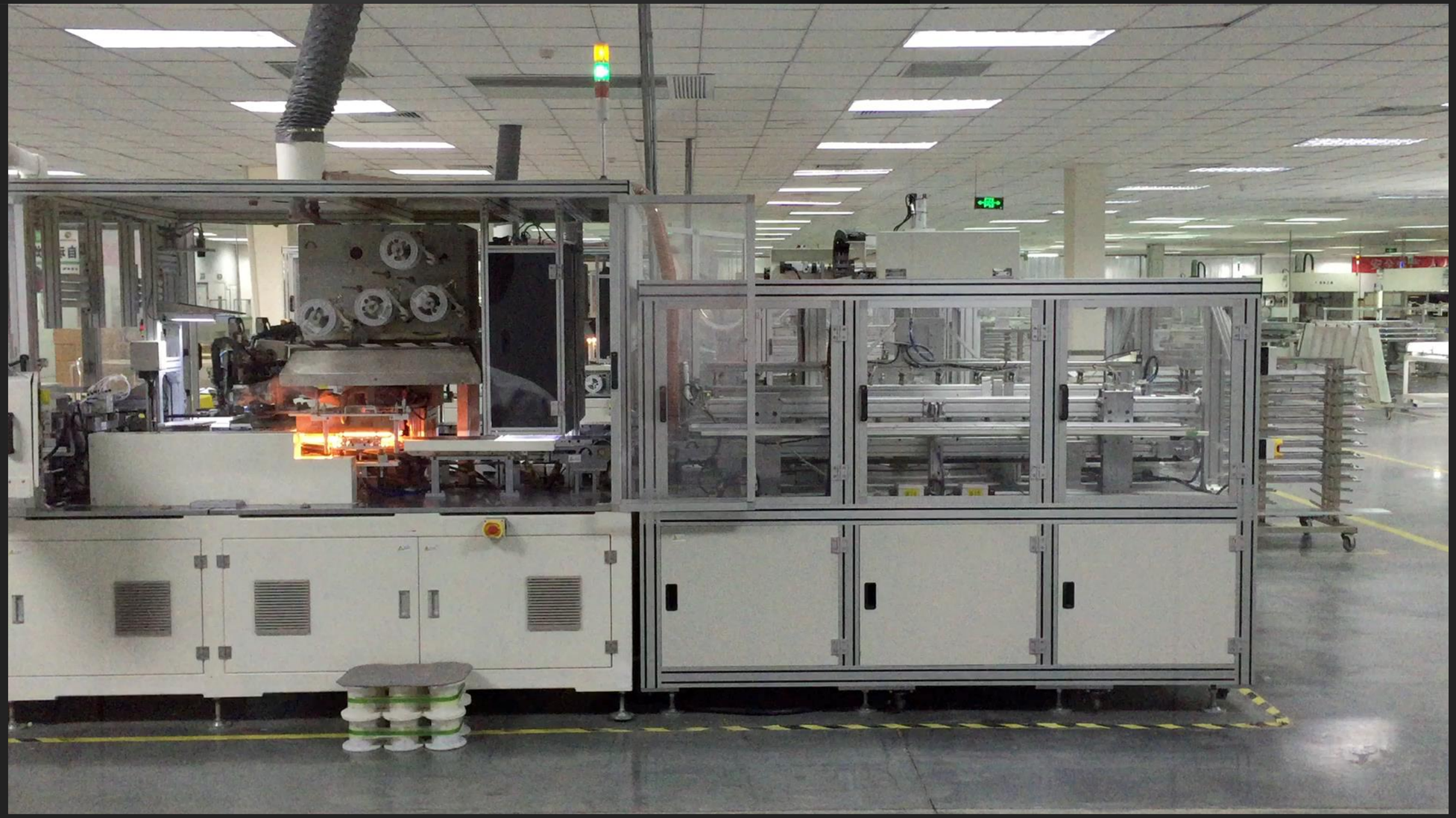








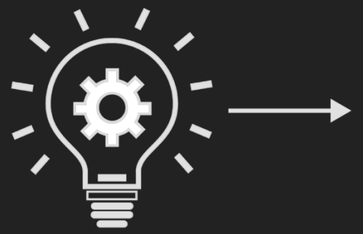

Technology Push
Niche Markets
Demand Pull
Scale up
1950
1960
1970
1980
1990
2000
2010
2020



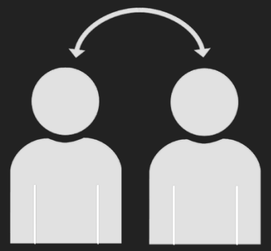
HOW DID SOLAR GET CHEAP?

CREATING TECHNOLOGY

SCIENTIFIC UNDERSTANDING



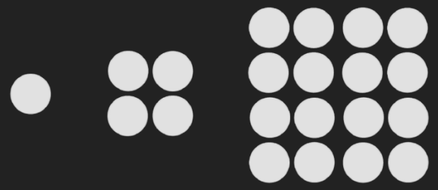
EVOLVING R&D FOCI



KNOWLEDGE SPILLOVER

BUILDING A MARKET

NICHE MARKETS

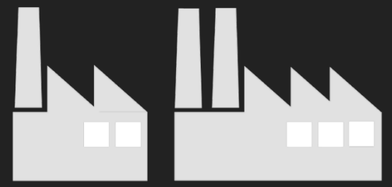


MODULAR SCALE

ROBUST POLICY SUPPORT

MAKING IT CHEAP

LEARNING BY DOING

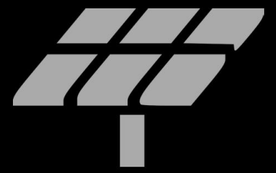
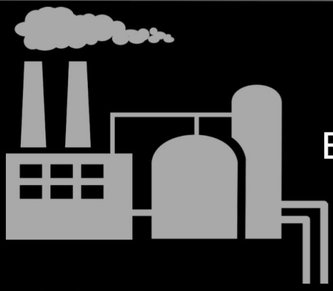
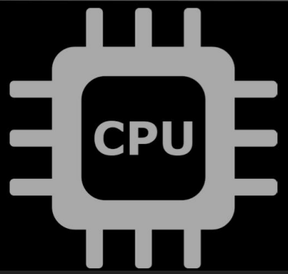
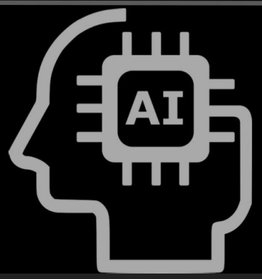


ITERATIVE UPSCALING

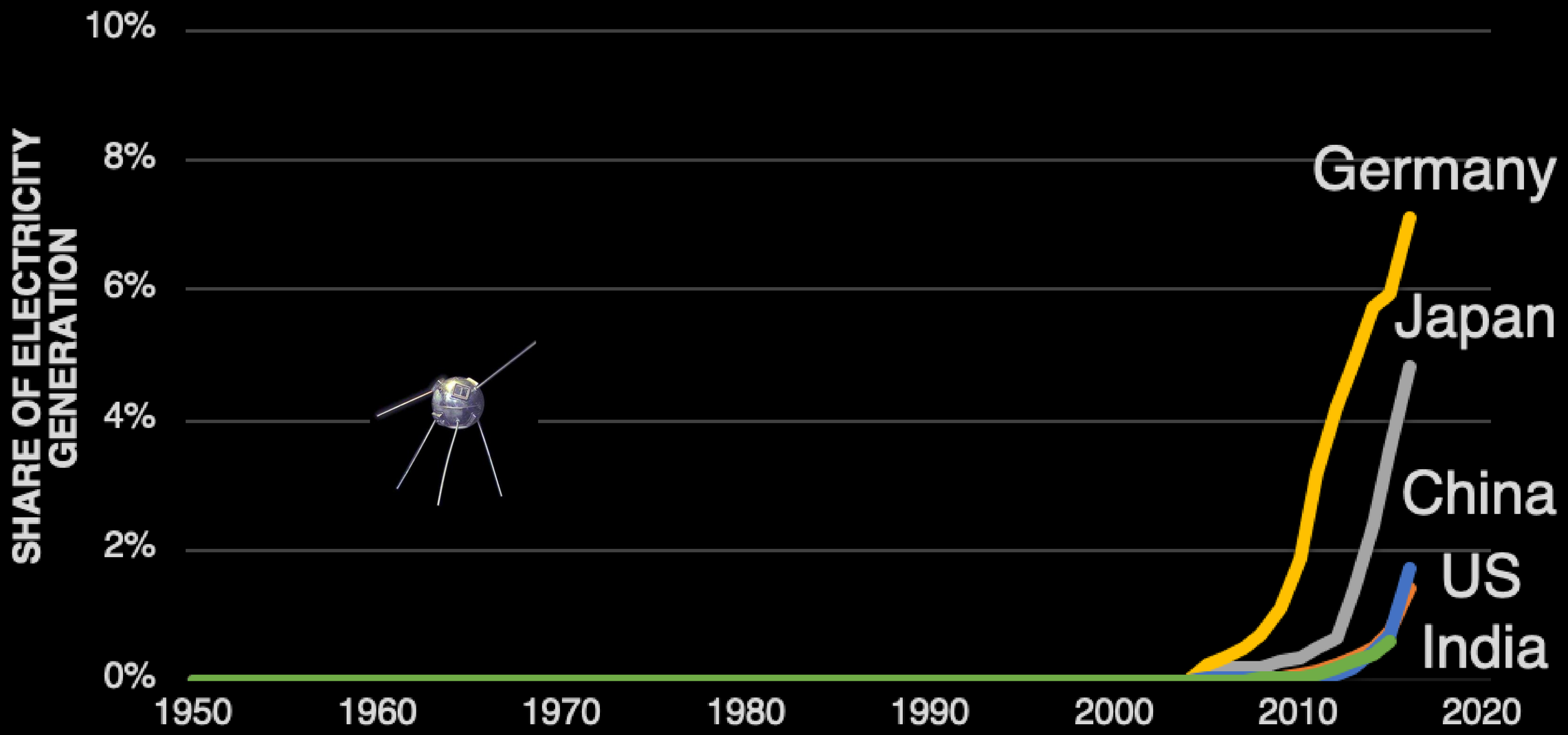
DELAYED SYSTEM INTEGRATION

PV AS ONE MODEL FOR LOW-CARBON INNOVATION

WE NEED MULTIPLE MODELS

Technology type	Innovation model	Low-carbon target
1. High-tech, iterative, disruptive	 Solar PV	 Direct air capture
2. Low-tech, small, distributed	 Green revolution	 Soils
3. Large, system integration intensive	 Chemical plants	 BECCS
4. General purpose	 Micro-processors	 Artificial intelligence

SHARE OF ELECTRICITY FROM PV



DACCS EXAMPLE

1st commercial 1957

Low cost 2017

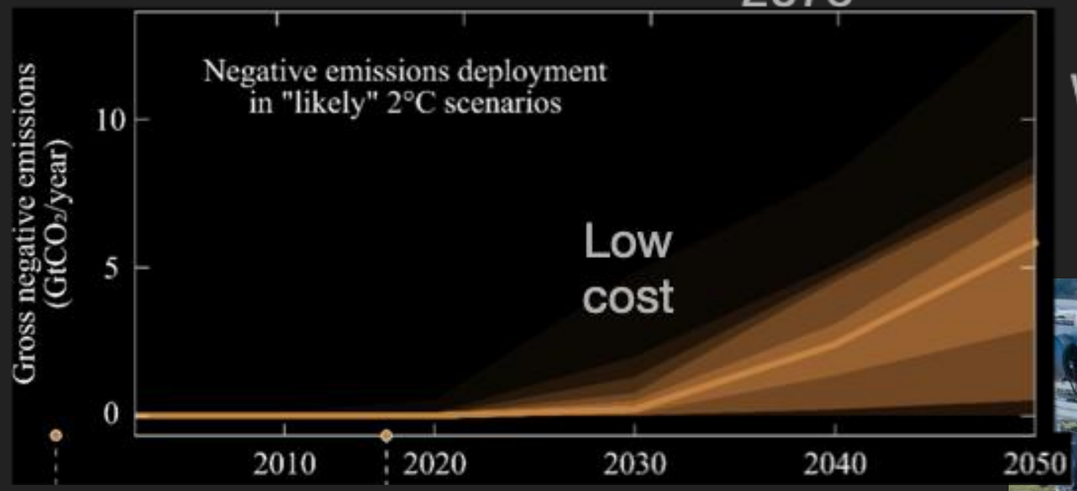
Widespread adoption 2040

DACCS

ClimeWorks 2017

Low cost 2076

Widespread adoption 2099



Widespread adoption

Accelerated model

ClimeWorks 2017

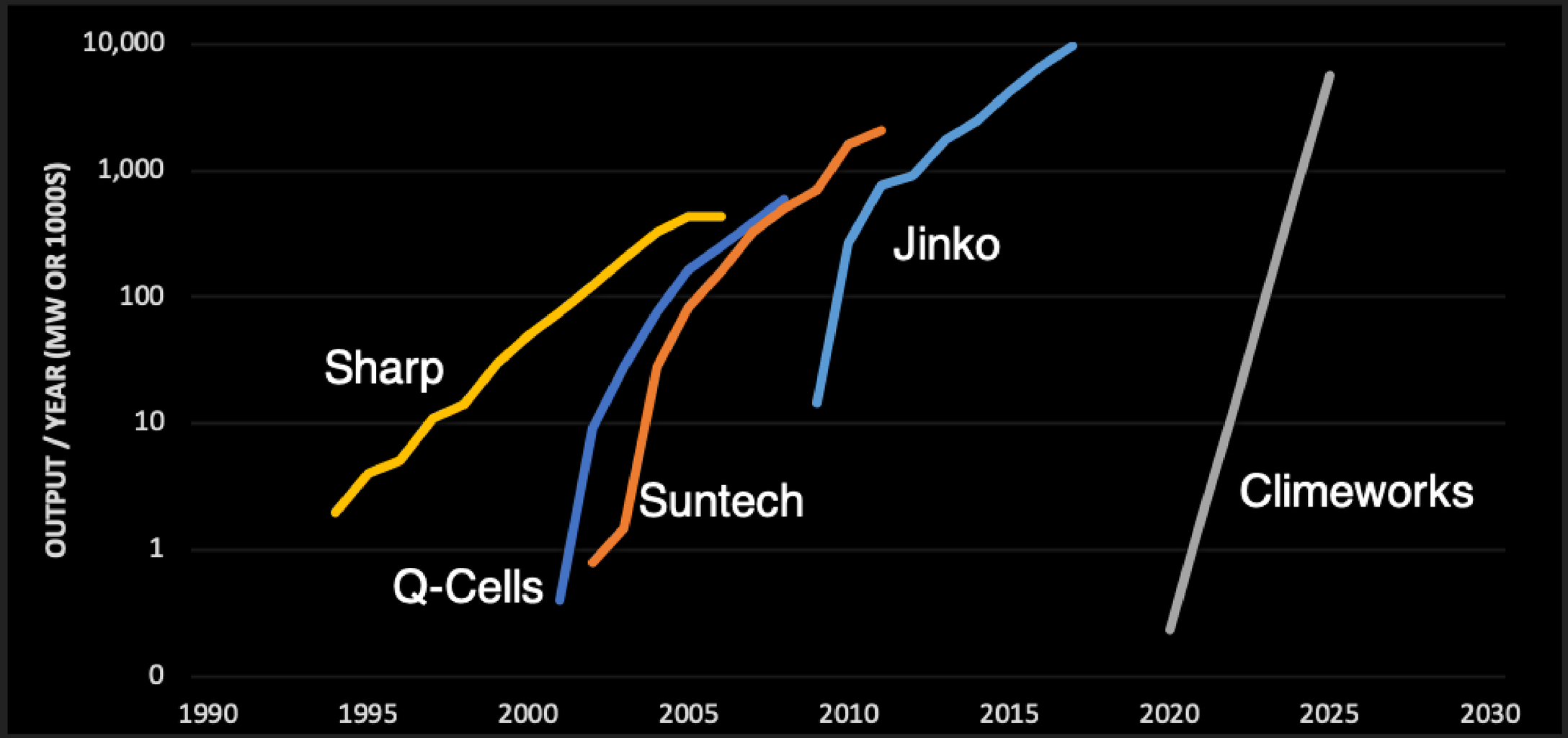
Low cost 2030

Widespread adoption 2060

Factor of 4 acceleration!

DACCS EXAMPLE

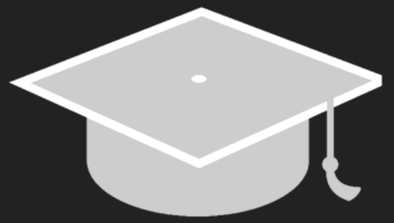
Scale-up needed for 1% of emissions by 2025 vs PV actuals



HOW TO ACCELERATE THE MODEL

TECHNOLOGY PUSH

CONTINUOUS R&D

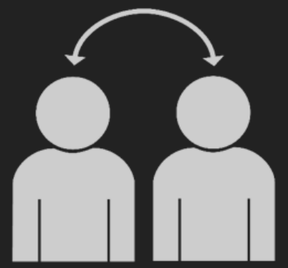


TRAINED WORKFORCE

PUBLIC PROCUREMENT

KNOWLEDGE FLOWS

CODIFY KNOWLEDGE

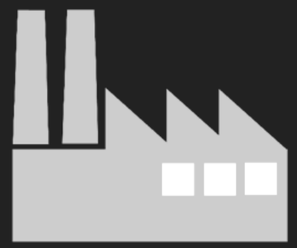


KNOWLEDGE SPILLOVER

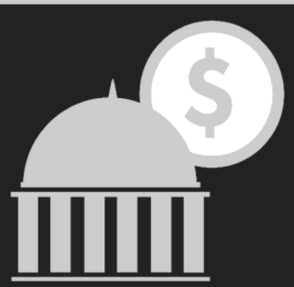
GLOBAL MOBILITY

DEMAND PULL

ROBUST MARKETS



DISRUPTIVE PRODUCTION



POLITICAL ECONOMY

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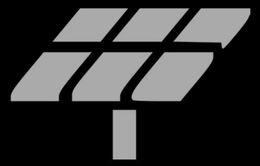
1. High-tech, iterative, disruptive	 Solar PV	 Direct air capture
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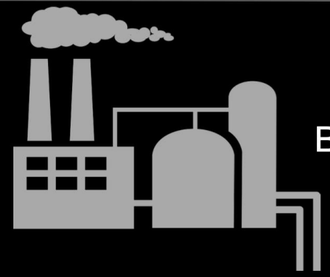
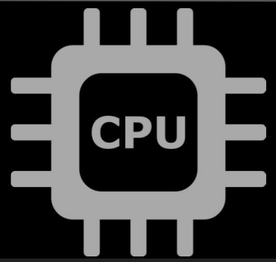
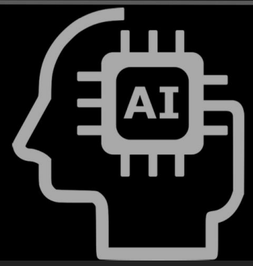
3. Large, system integration intensive	 Chemical plants	 BECCS
4. General purpose	 Micro-processors	 Artificial intelligence