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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Clean Energy Technology Pathways from Research to Commercialization: Policy and Practice Case Studies

Jill A. Engel-Cox, Wyatt G. Merrill, Marie K. Mapes, Ben C. McKenney, Antonio M. Bouza, Edgar DeMeo, Mary Hubbard, Eric L. Miller, Richard Tusing, Brian J. Walker

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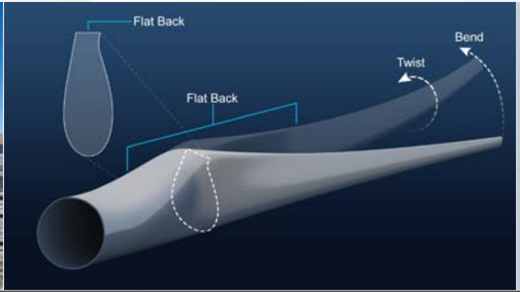

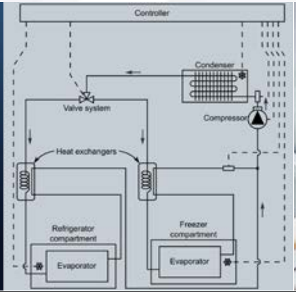

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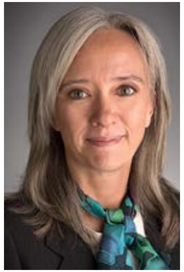
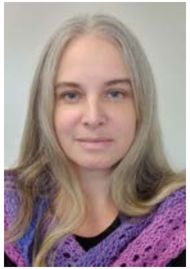
Introductions

Presenters



Jill Engel-Cox
Senior Research Advisor
National Renewable Energy Laboratory



Marie Mapes
Technology Manager, Solar Energy Technologies Office
Office of Energy Efficiency and Renewable Energy

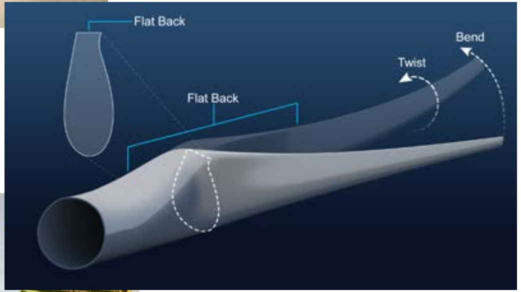
Wyatt Merrill
Technology Manager, Solid-State Lighting and Building Electric Appliances, Devices, and Systems
Office of Energy Efficiency and Renewable Energy

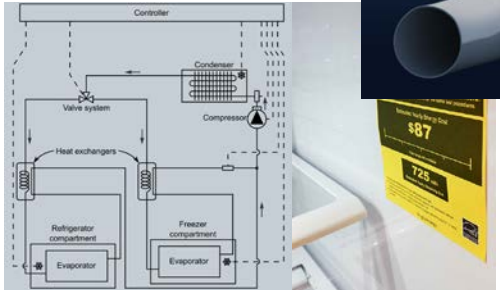
Brian Walker
Technology Manager, Building-to-Grid and Controls
Office of Energy Efficiency and Renewable Energy

Additional Coauthors: Ben C. McKenney, Antonio M. Bouza, Edgar DeMeo, Mary Hubbard, Eric L. Miller, Richard Tusing

Outline

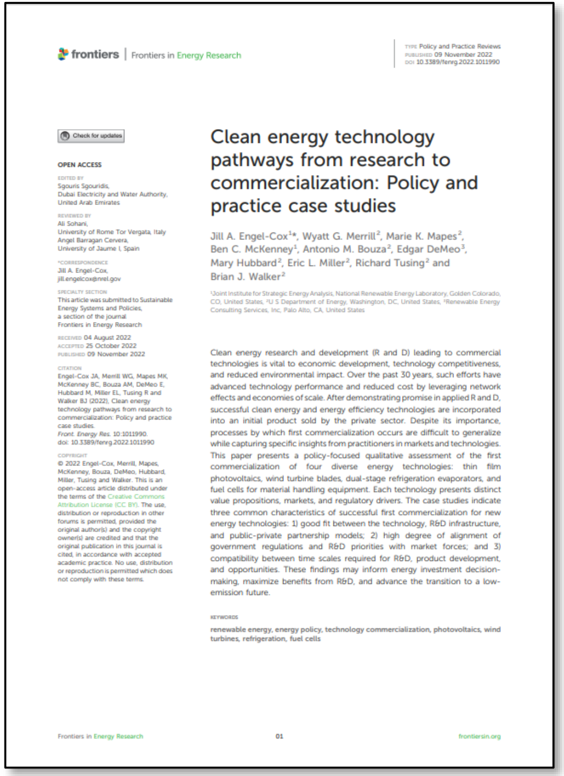
- Purpose and Methodology
- Four Case Studies
  - Thin film solar photovoltaics
  - Fuel cells for material handling equipment
  - Wind blade improvements
  - Efficiency in refrigerators
- Summary of Findings
- Questions and Discussion





Question: How does clean energy go commercial?

- What technologies are we talking about, and why are they different?
- How do relevant innovations happen?
- How does market entry happen?
- There are ways to answer some of these questions
  - Detailed history
  - Track patents and products
  - Impact analysis
- What are the most valuable cases and insights from EERE’s memory?



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Clean energy technology pathways from research to commercialization: Policy and practice case studies

Jill A. Engel-Cox[1]*, Wyatt G. Merrill[2], Marie K. Mapes[2], Ben C. McKenney[1], Antonio M. Bouza[2], Edgar DeMeo[3], Mary Hubbard[2], Eric L. Miller[2], Richard Tusing[2] and Brian J. Walker[2]

[1]Joint Institute for Strategic Energy Analysis, National Renewable Energy Laboratory, Golden Colorado, CO, United States, [2]U S Department of Energy, Washington, DC, United States, [3]Renewable Energy Consulting Services, Inc, Palo Alto, CA, United States

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EDITED BY
Sgouris Sgouridis,
Dubai Electricity and Water Authority,
United Arab Emirates

REVIEWED BY
Ali Sohani,
University of Rome Tor Vergata, Italy
Angel Barragan Cervera,
University of Jaume I, Spain

*CORRESPONDENCE
Jill A. Engel-Cox,
jill.engelcox@nrel.gov

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Clean energy research and development (R and D) leading to commercial technologies is vital to economic development, technology competitiveness, and reduced environmental impact. Over the past 30 years, such efforts have advanced technology performance and reduced cost by leveraging network effects and economies of scale. After demonstrating promise in applied R and D, successful clean energy and energy efficiency technologies are incorporated into an initial product sold by the private sector. Despite its importance, processes by which first commercialization occurs are difficult to generalize while capturing specific insights from practitioners in markets and technologies. This paper presents a policy-focused qualitative assessment of the first commercialization of four diverse energy technologies: thin film photovoltaics, wind turbine blades, dual-stage refrigeration evaporators, and fuel cells for material handling equipment. Each technology presents distinct value propositions, markets, and regulatory drivers. The case studies indicate three common characteristics of successful first commercialization for new energy technologies: 1) good fit between the technology, R&D infrastructure, and public-private partnership models; 2) high degree of alignment of government regulations and R&D priorities with market forces; and 3) compatibility between time scales required for R&D, product development, and opportunities. These findings may inform energy investment decision-making, maximize benefits from R&D, and advance the transition to a low-emission future.

KEYWORDS
renewable energy, energy policy, technology commercialization, photovoltaics, wind turbines, refrigeration, fuel cells

Purpose and Methodology

Purpose

- Identify generalizable approaches
- Inform research investment
- Advance the transition to a low-emission future

Methodology

- Synthesize findings from interviews with 50+ subject matter experts (1:1s, panels, and workshops)

Case Study Selection

- Diversity of technology type (clean energy and energy efficiency)
- Diversity of commercialization approaches and strategies
- Fully commercialized technology with DOE participation

Thin Film Cadmium Telluride (CdTe) Solar Photovoltaics

Photo by Dennis Schroeder, NREL

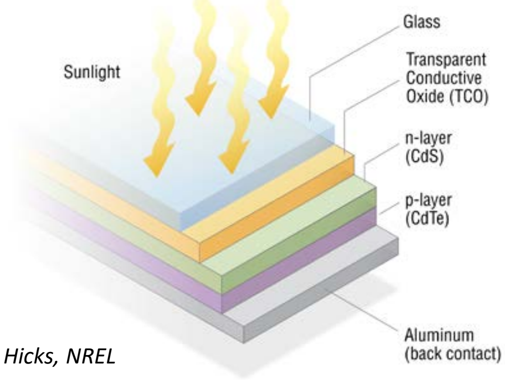
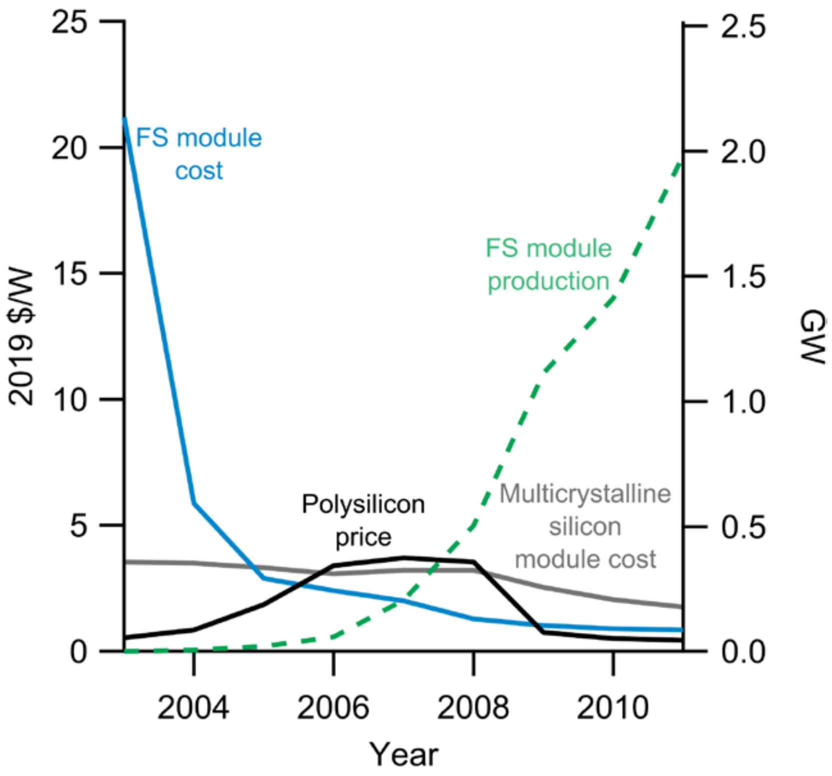


Illustration by Alfred Hicks, NREL

- Nascent competitive industry
- Decades of R&D partnership among First Solar, DOE national labs, and universities
  - Increase cell efficiency
  - High-rate vapor transport deposition manufacturing
  - Testing and validation for reliability
- Life-cycle analysis and recycling commitments enabled access to early growing German solar market

Thin Film CdTe PV – Keys to Success



Data sources: First Solar Inc, 2020; Bernreuter Research, 2020; Photon Energy Group, 2020

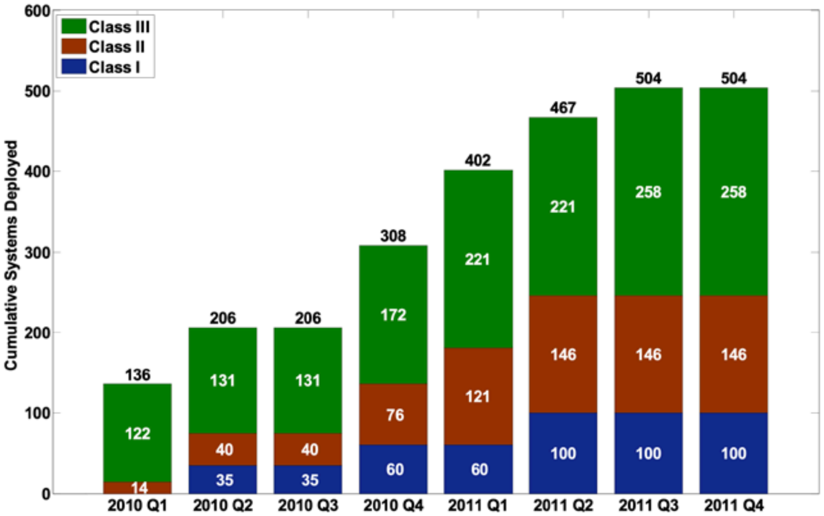
- Government funding enabled:
  - Foundational materials research
  - Advanced manufacturing methods
  - Consistent testing standards
- Production, capacity, manufacturing innovation enabled decrease in CdTe module price per watt
  - Price dropped below silicon modules from mid-2000s to mid-2010s
- Company management proactively addressed product environmental concern
- Prepared company could take advantage of an open market opportunity

Fuel Cells for Material Handling Equipment

Photo by Jennifer Kurtz, NREL

- Forklifts and other material handling equipment (MHE) operating with hydrogen (H_2) powered fuel cells
- Established industry with need for
  - Low air emission power for indoor warehouses
  - Rapid fueling compared to lead-acid batteries
- Research community seeking successful commercialization in transportation market
- Competitive awards to industry, funded
  - Deployment of 100s H_2 fuel cell powered MHEs at industrial and Defense Department sites
  - Installation of supportive infrastructure for fueling, data collection, training

Fuel Cells for MHE – Keys to Success



Source: NREL, https://www.nrel.gov/docs/fy12osti/55308.pdf

- Over 500 deployed launched successful first market manufacturing at scale resulting in >40,000 units integrated within industry
  - Provided energy density, fast refueling, fuel storage capacities
- Government funding enabled:
  - Foundational research in fuel cell development
  - Testing/demonstration collaboration with industry
  - Direct procurement of early commercial technologies
- Fuel cell MHEs overlapped technology readiness and markets by new competitive alternative technologies

Wind Blade Design Improvements

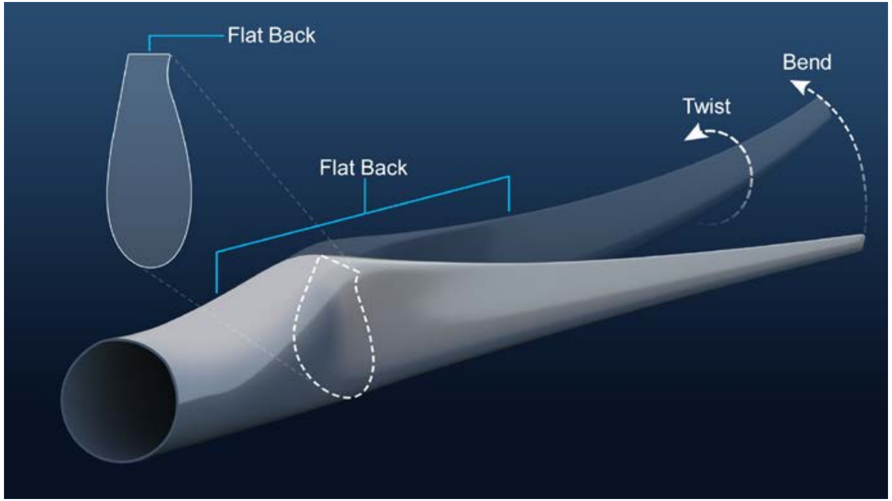
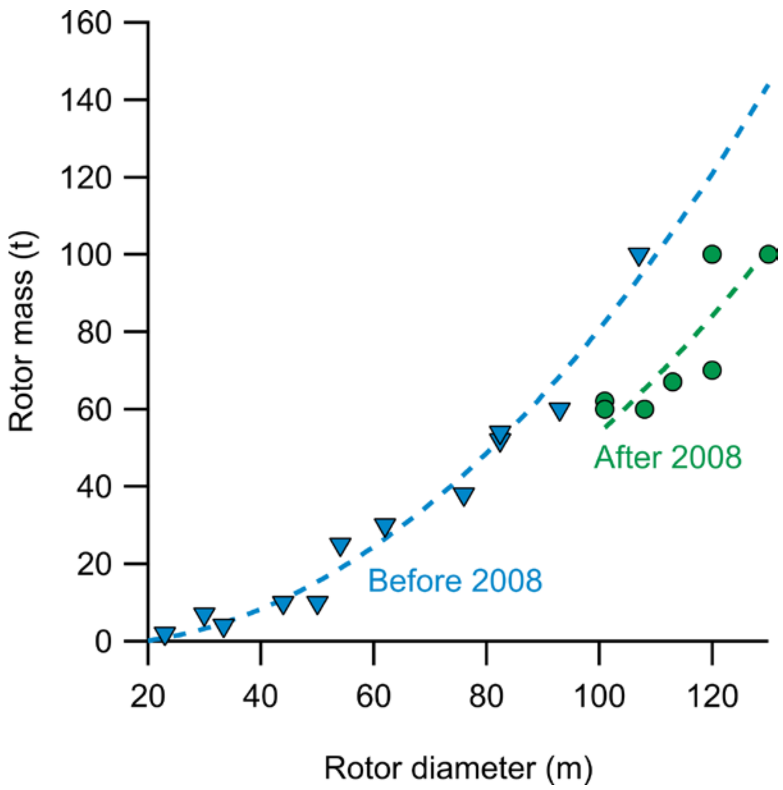


Illustration by Besiki Kazaishvili, NREL

- Nascent competitive industry
- Funded ecosystem of universities, national labs, and private startup companies advanced innovations
  - Bend-twist design passively reduces pitch, lowering load during wind gusts
  - Flat-back design structurally enhances connection to hub keeping airfoil blades
  - Combination enabled longer blades with less mass
- Designs presented in open fora and proven in shared government testing facilities

Wind Blade Design Improvements – Keys to Success



Data source: thewindpower.net, 2020

- Significant reduction in scaling trends enabled larger rotors and lower (~33%) levelized cost of energy
  - Resulted in rapid expansion after 2008 to $100 billion annual worldwide market
- Government funding enabled:
  - Convening for innovation across public-private organizations
  - Shared research and testing user facilities
- Selectively open intellectual property
  - Fundamental design principles open to all
  - Companies applied principles in their own proprietary designs

Efficiency in Refrigerators

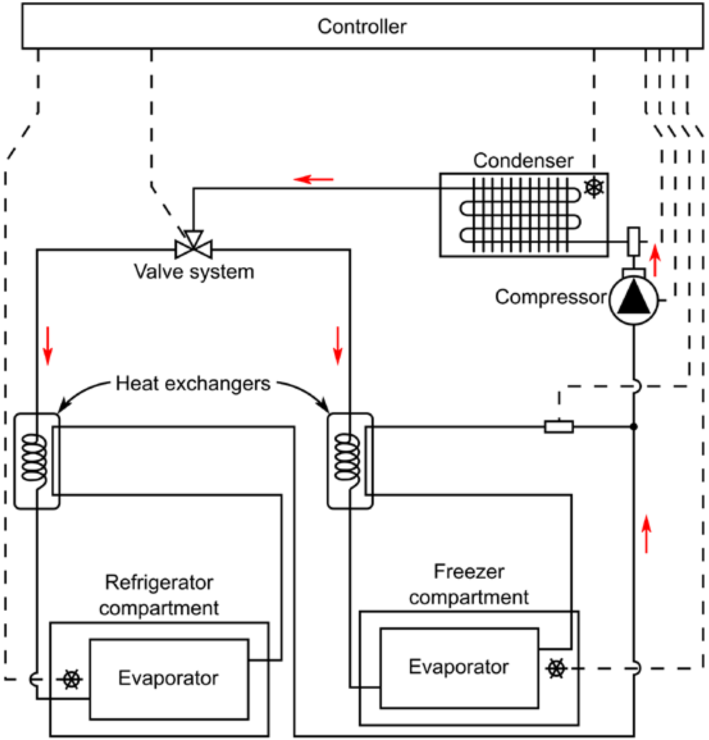
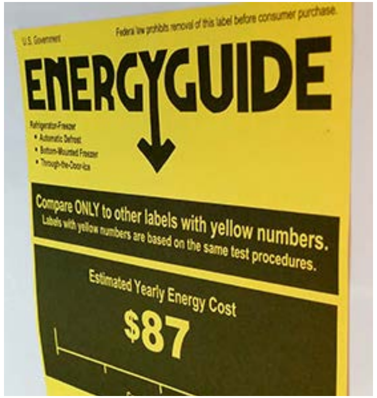


Diagram adapted from U.S. Patent 9285161B2, Dual Evaporator Development for Refrigerators

- Dual evaporators for fresh food and freezer compartments in refrigerators to increase efficiency
- Established industry with
  - Minimum efficiency standards periodically updated by DOE
  - Low margin with price sensitive customers
- Cooperative research between Whirlpool and DOE funded by American Recovery and Reinvestment Act
  - Access to national laboratory simulation tools and advanced experimental facilities
  - Resulted in patents for commercialized design with improved efficiency

Efficiency in Refrigerators – Keys to Success

- Demonstrated >50% energy reduction per unit volume with small cost increase
- Government action and funding enabled:
  - Regulatory standards as driver for innovation in established low margin market
  - Access to funded R&D assets, including models, test facilities, and funded researchers



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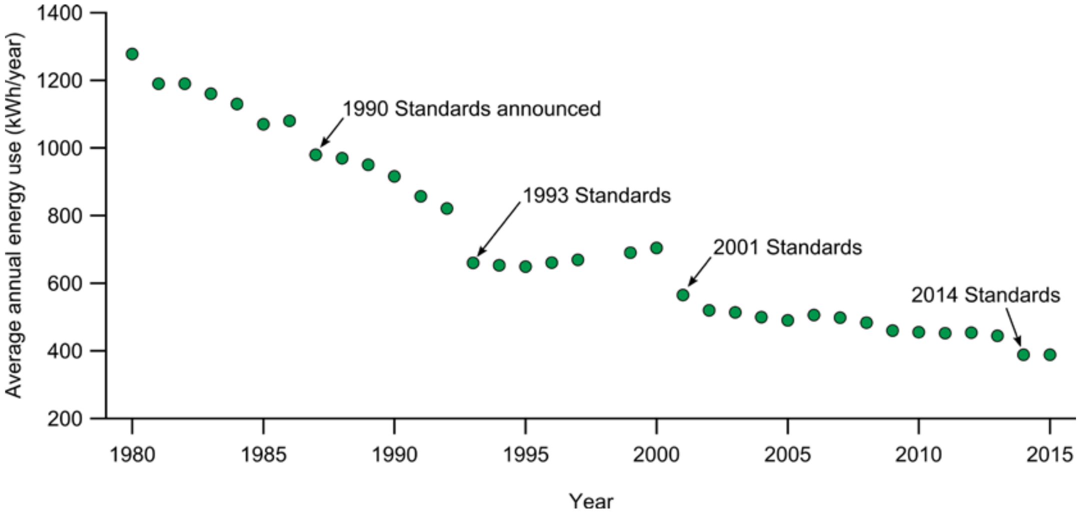


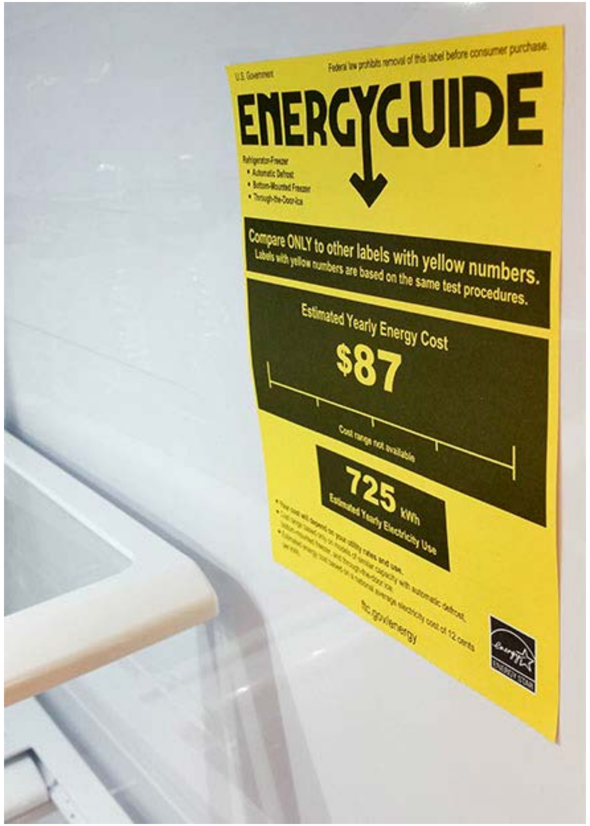
Data sources: Rosenfeld, 1999; Aham.org, 2018; Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers, 2010

Summary and Conclusions

Technology *and Initial Status*	**Public-Private Partners** *and Partnership Type*	**Alignment of Government and Market**	**Compatibility of Development Timing**
Thin Film Solar Photovoltaics *Nascent technology*	Startup company; National labs and universities *Shared standards and research*	Government cost goals and performance standards; Market seeking affordable clean energy	Jointly developed cost and recycling solutions met market timing
Wind Blade Improvements *Nascent industry*	Startup and established companies; Universities and national labs *Open R&D consortium*	Shared research user facilities; Open intellectual property; Increased market demand	Technology widely adopted and adapted by accelerating industry
Dual-stage Refrigeration Evaporators *Established industry*	Established company; National lab *Cooperative R&D agreement*	Efficiency standards mandated by statute; Models requested by industry from national labs	Technology solutions met standards deadline and launched other technology options
Fuel Cells for Material Handling Equipment *New application*	Startup companies; Government operations facilities *Demonstration grants*	R&D advanced technology performance; Market demand for cleaner options for current equipment	Demonstrations enabled accelerated development of this and other technology options

Conclusions and Policy Implications

- **Company leaders:** Successful energy technology companies leverage research infrastructure and partnerships to be prepared for market opportunities
- **Government program managers:** Array of policy tools support first commercialization – research funding, shared-use facilities, technology targets, open innovation, deployment incentives
- **Proposed future approach:** Proactive longitudinal studies with measurable inputs and success metrics tracked over decade of development from research → first commercialization



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Thank you! Questions?

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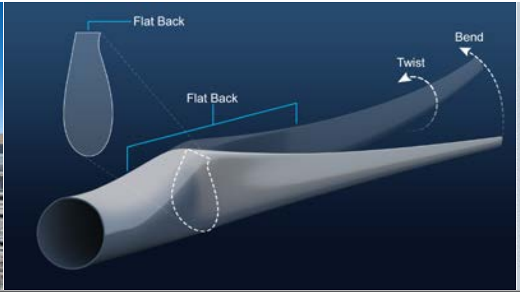

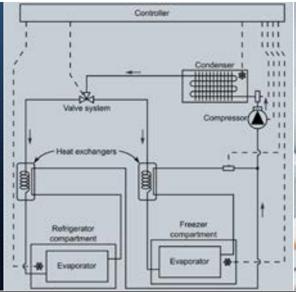

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