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Applied Materials

Nanomanufacturing Innovations For Electronics, Display & Energy: Opportunities and Challenges

OUTLINE

- Introduction to Applied Materials
- Nanotechnology vs Nanomanufacturing
- Nanomanufacturing for Electronics & Display
- Nanomanufacturing for Energy: Global Drivers, Technology Inflections and Need for Innovative Solutions
- Call for Action and Summary

Applied Materials – Who We Are

- Founded in 1967 in Silicon Valley

- Extensive global interactions
  - Operate in > 20 countries
  - Revenue typically > 80% outside US

Nanomanufacturing Technology

Small features on a large production scale

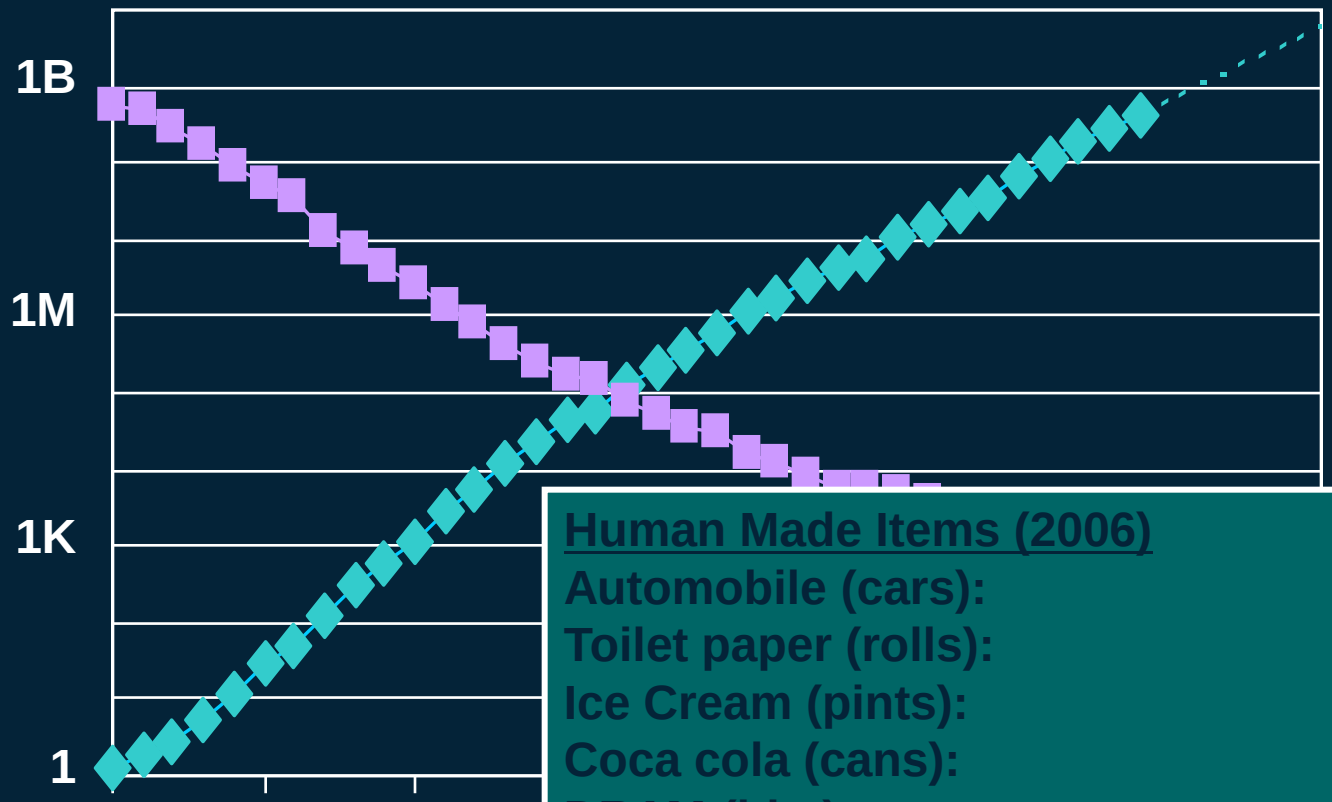
Placing a nanotube?

Scale Up?

Additional Innovation

More Than Nanofabrication – Repeatable, Robust, Reliable, Controllable: Scalable & Cost Effective Solution

Moore's Law and Transistor Cost



Number of Transistors (x Billions)

Human Made Items (2006)	
Automobile (cars):	65,000,000
Toilet paper (rolls):	2,100,000,000
Ice Cream (pints):	32,000,000,000
Coca cola (cans):	290,000,000,000
DRAM (bits):	2,900,000,000,000,000,000
Flash (bits):	3,500,000,000,000,000,000

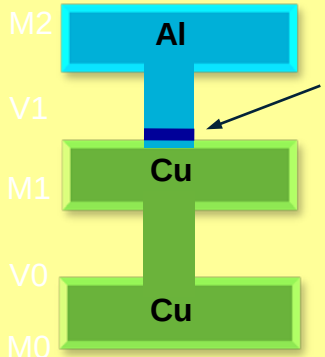
(Source: G. Moore, ISSCC 2003)

Exa-bits at Nano-dollars

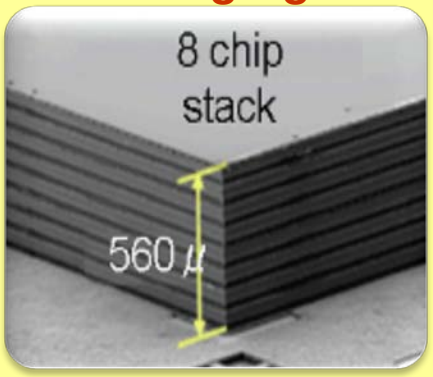
Disruptions in ITRS Roadmap

Patterning

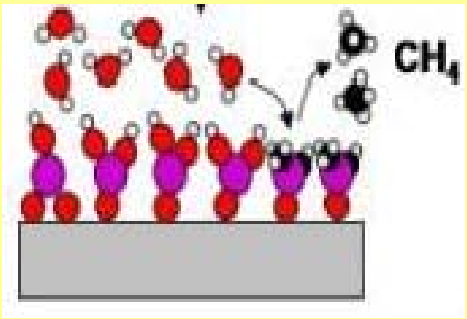
Interconnects



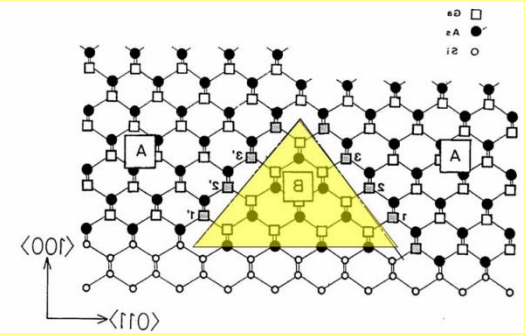
Packaging



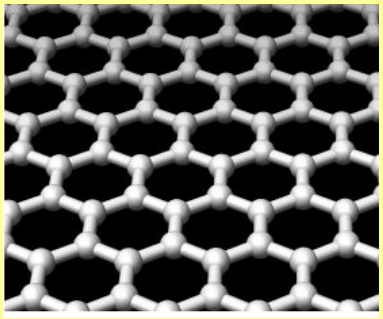
ALD



III-V on Si, Vertical Transistors

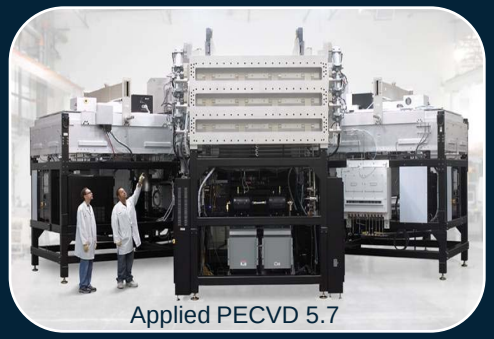


New Materials&Memories



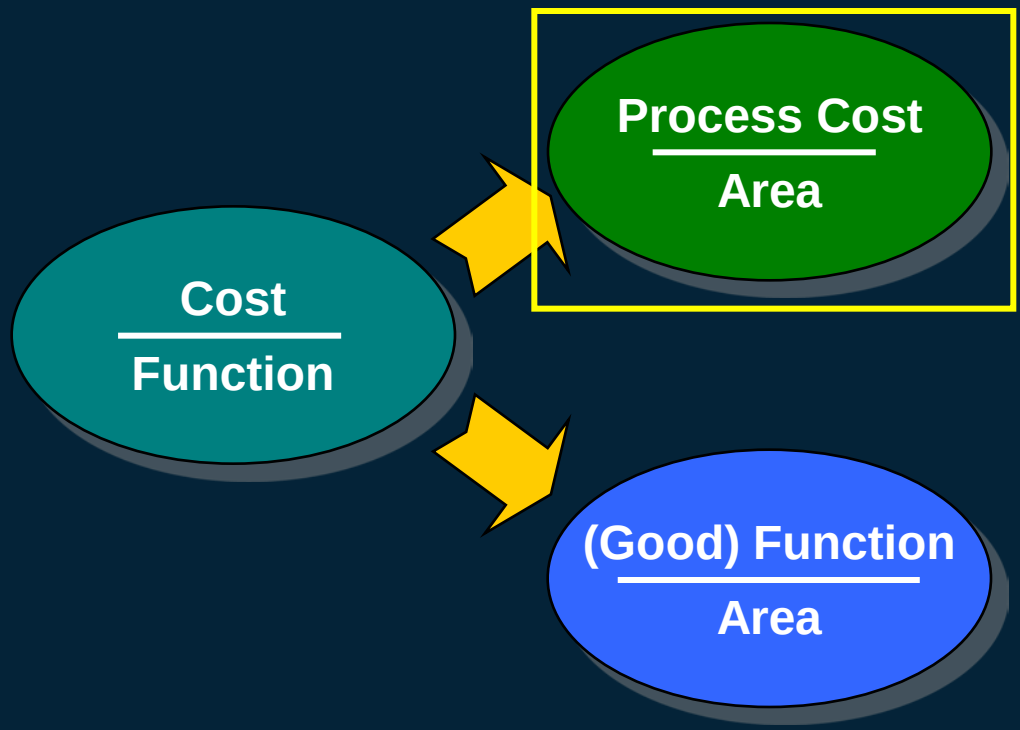
The Road to 10 nm is Full of Fundamental Challenges and Disruptions

Cost Per Function: Flat Panel Displays


Applied PECVD 5.7


AKT-PIVOT™ 55KV PVD

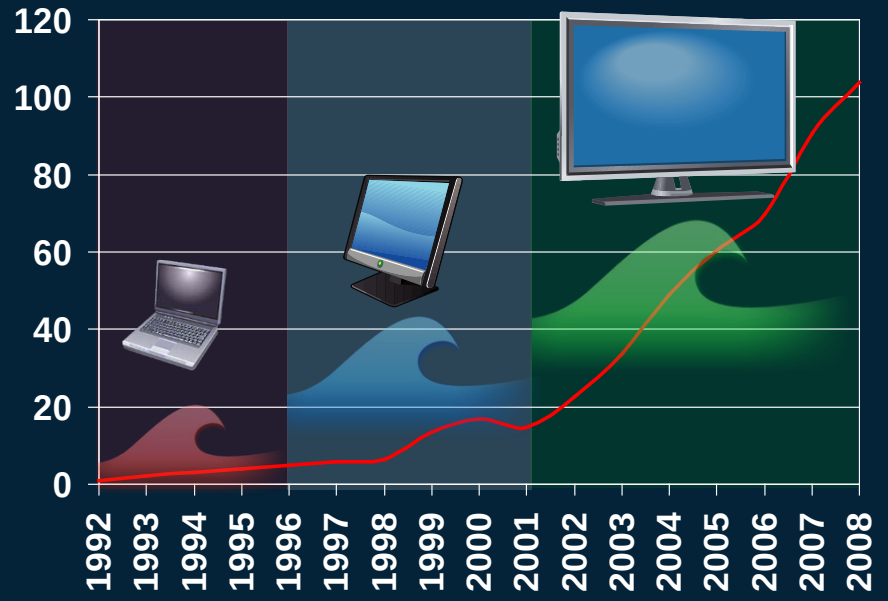

Courtesy Sharp



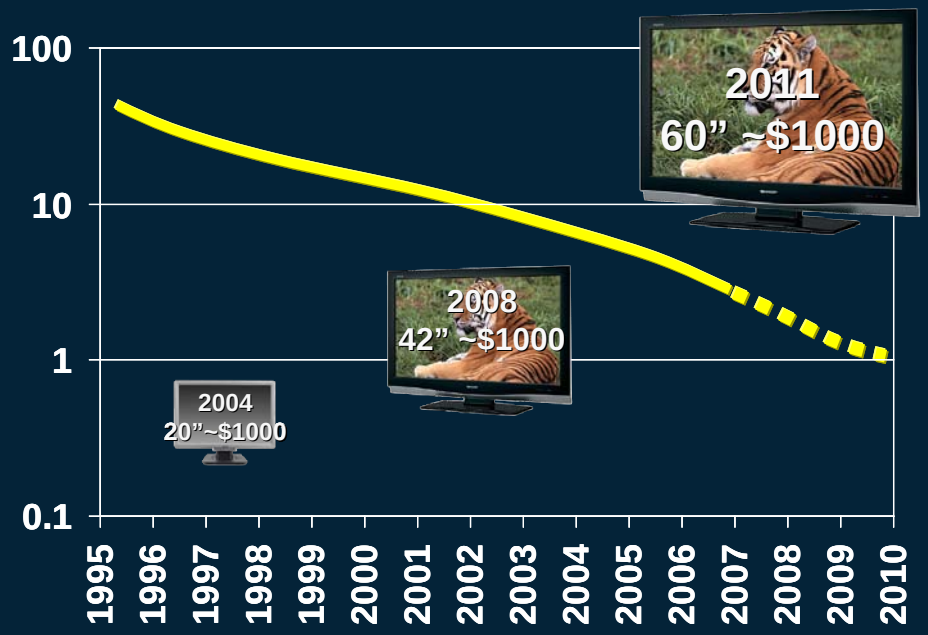
- Functions/area is the predominant driver for VLSI
- Cost/area is the more dominant factor in applications other than VLSI

Flat Panel Display (LCD) Manufacturing

LCD Industry Revenue ($B)

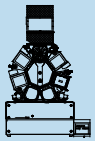
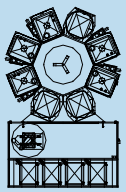
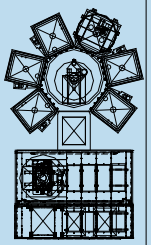
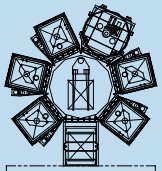
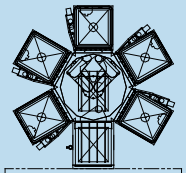
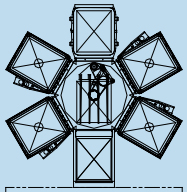
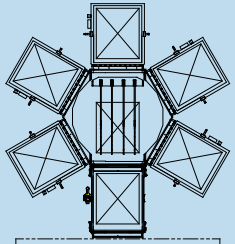
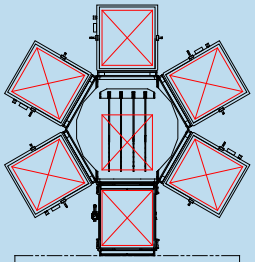


Production Cost per Area (k$/m^2)



> 20% Bigger (HD)TV Every Year for the Same Price

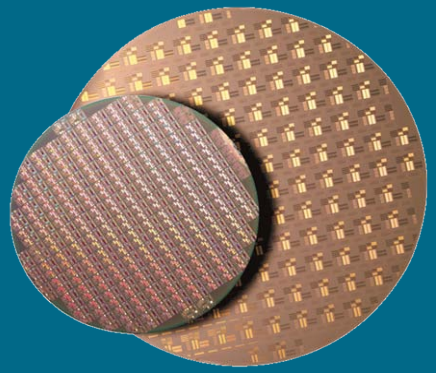
Flat Panel Display Equipment – PECVD

	Gen 2	Gen 3 / 3.5	Gen 4	Gen 5	Gen 5	Gen 5.5	Gen 6	Gen 7 / 7.5	Gen 8
1st Release	2/ '93~	4/ '95~	1/ '00~	8/ '01~	6/ '02~	8/ '04~	5/ '03~	7/ '04~	2006
System Layout					 ACLS	 ACLS	 ACLS	 ACLS	 ACLS
Model	1000	2500 / 4300 / 4300A	5500/5500A	10K	10K / 10KA	15K	15K / 15KA	25K / 25KA	40K / 40KA
Substrate Size (mm)	370x470 400x500	550x650 600x720	680x880 730x920	1000x1200	1100x1250 1200x1400	1300x1500	1500x1800 1500x1850	1870x2200 1950x2250	2160x2460
Substrate Area	1,740 cm2 (1.00)	4,650 cm2 (2.33 from 1600)	6,270 cm2 (1.44 from 4300)	7,770 cm2 (1.79 from 5500)	5,650 cm2 (1.30 from 10K)	5,430 cm2 (1.25 from 15 K)	7,750 cm2 (1.78 from 15 K)	6,630 cm2 (1.52 from 25 K)	5,270 cm2 (1.21 from 40 KA)

Gen 10 = 60nm uniformity over ~ 10^{19} nm^2 area at 50sph

Applied Materials Enables and Expands Markets by Driving Cost Reduction….

FIRST



Cost per transistor

1974	2004
4 trillion	1,400,000 trillion
10 cents	5 nano-dollars

20,000,000x Cost Reduction

Source: SIA, IC Knowledge LLC

THEN

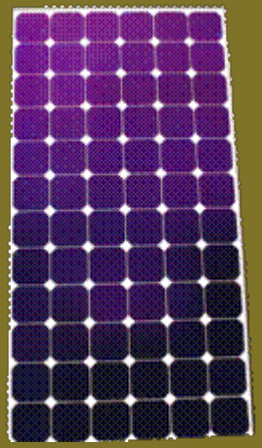
Cost per area

1995	2005
0.3 million m^2	25 million m^2
$30,000/$m^2$	$1,500/$m^2$

20x Cost Reduction

Source: Display Search, Nikkei BP, Applied Materials

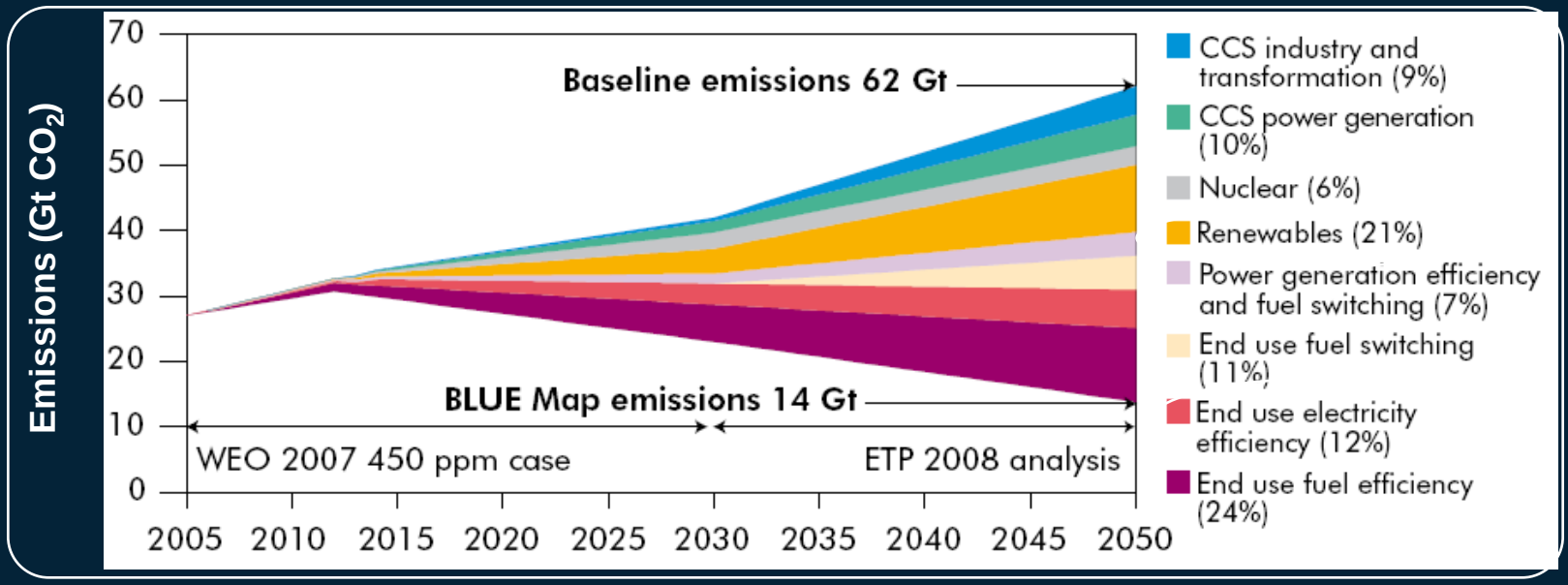
NOW



Cost per watt

Global Energy Opportunity

Comparison of the World Energy outlook 2007 450ppm case and the Blue Map Scenario, 2005-2050



- Global economy is set to grow four fold and could approach tenfold in developing countries in 2007-2050 period
- Global "business-as-usual" will increase CO_2 emissions by 130% raising global temperatures by 6ºC
- Over $45 trillion dollars need to be invested to reduce the CO_2 emissions by 50% or $17 trillion to maintain today's emission levels

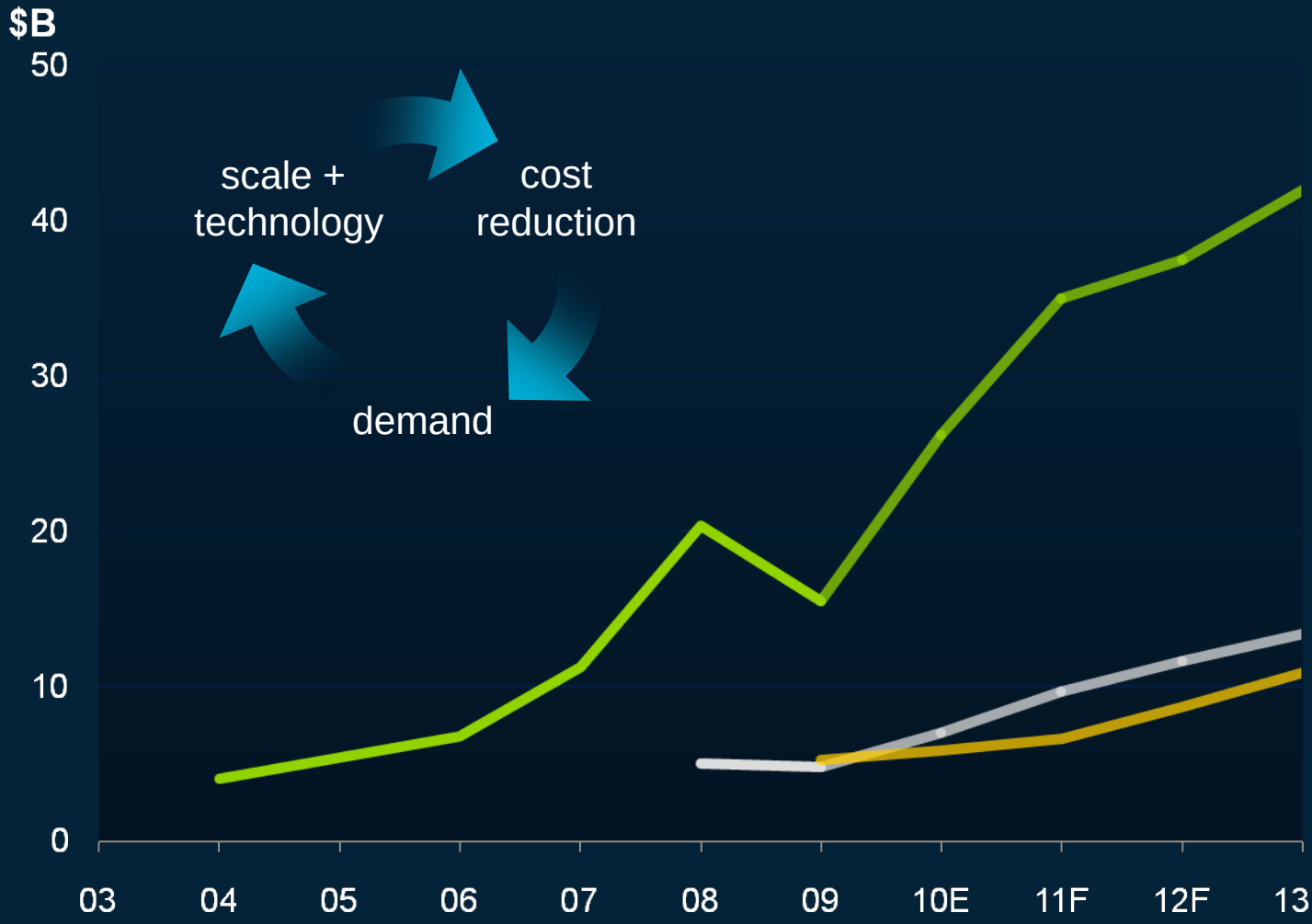
Source: World Energy Outlook, Source : IEA, Energy Technology Perspectives 2008

Energy Technology Innovations

Supply side	Demand side
■ CCS fossil-fuel power generation	■ Energy efficiency in buildings and appliances
■ Nuclear power plants	■ Heat pumps
■ Onshore and offshore wind	■ Solar space and water heating
■ Biomass integrated-gasification combined-cycle and co-combustion	■ Energy efficiency in transport
■ Photovoltaic systems	■ Electric and plug-in vehicles
■ Concentrating solar power	■ H_2 fuel cell vehicles
■ Coal: integrated-gasification combined-cycle	■ CCS in industry, H_2 and fuel transformation
■ Coal: ultra-supercritical	■ Industrial motor systems
■ Second-generation biofuels	

- IEA identified 17 critical technologies on demand and supply side to address energy efficiency, generation and transportation innovations necessary to fuel global growth

Energy Technology Markets



CAGR '10 – '13F

GENERATION
Solar PV
(~25%)

CONSERVATION
LED
(~24%)

STORAGE
Li-Ion battery
(~20%)

Source: SIA, Display Search, Photon Consulting, Bank of America-Merrill Lynch, IIT Japan, Avicenne, BCC

Energy Efficiency - Opportunity

- **Buildings** account for 40% of primary energy and 73% of electricity use

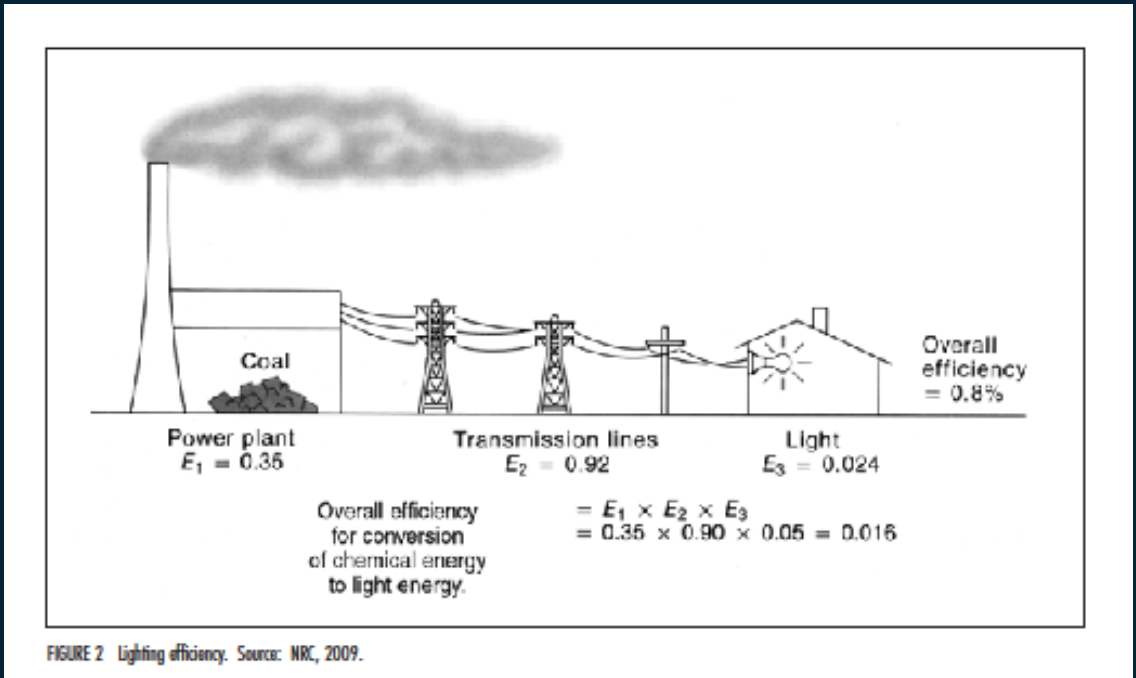
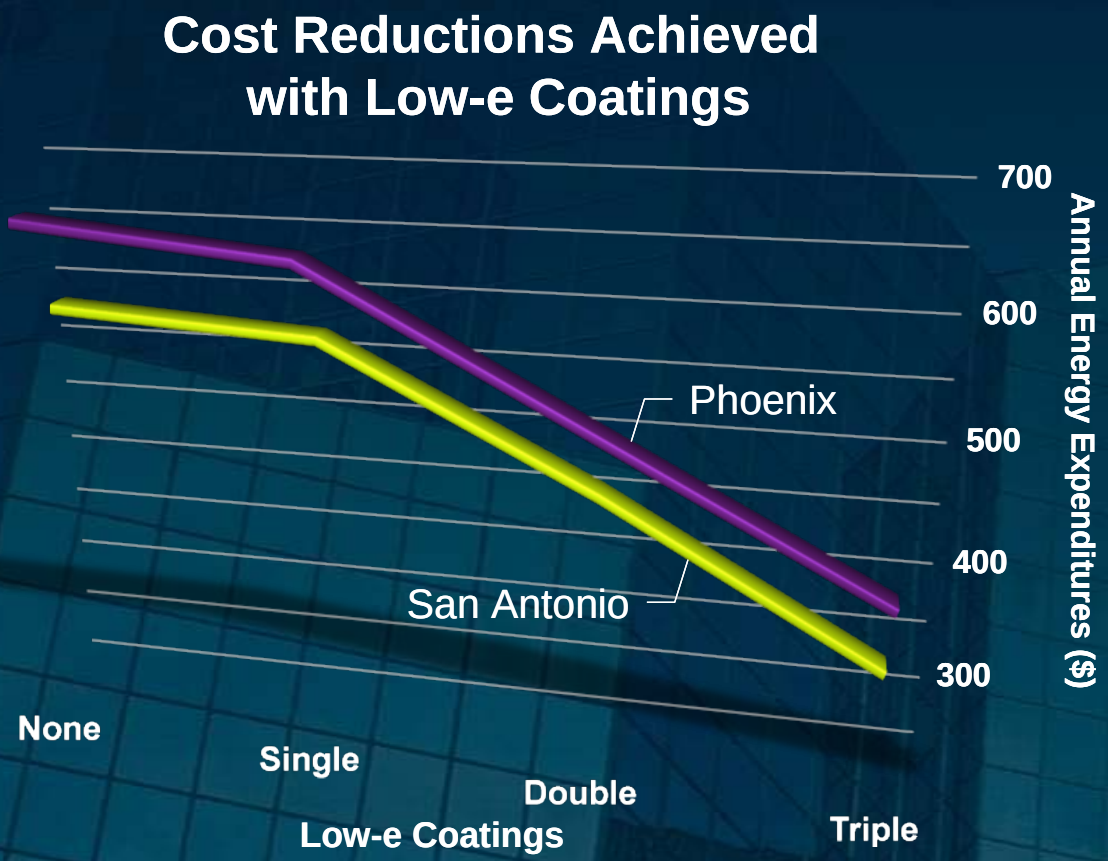


FIGURE 2 Lighting efficiency. Source: NRC, 2009.

- **Lighting** consumes 22% of electricity
  - Plant to light efficiency for incandescent lamps is only 0.8% but can go up 10 fold with LED lighting to 8%

Source: National Academy of engineering

Reducing HVAC Energy: Architectural Coated Glass



2000 ft2 house with 300 ft2 of windows

Annual Energy Loss (U.S.) Due to Today's Windows: ~ 4.5Q BTUs* (6% total energy usage, cost >$40B)

Increasing Adoption of Coated Glass

Savings from 2007 Global Output ~ 36,000 Bbl/day†

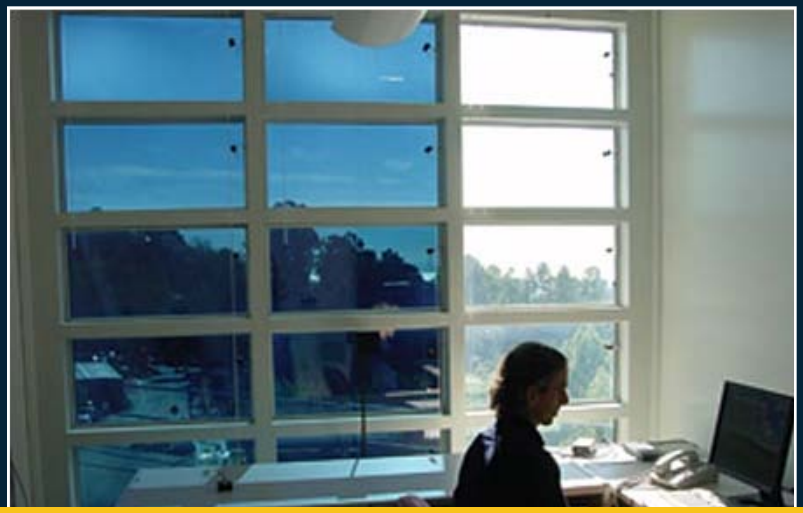
† Equivalent to 12 oil wells or 18Mt CO_2

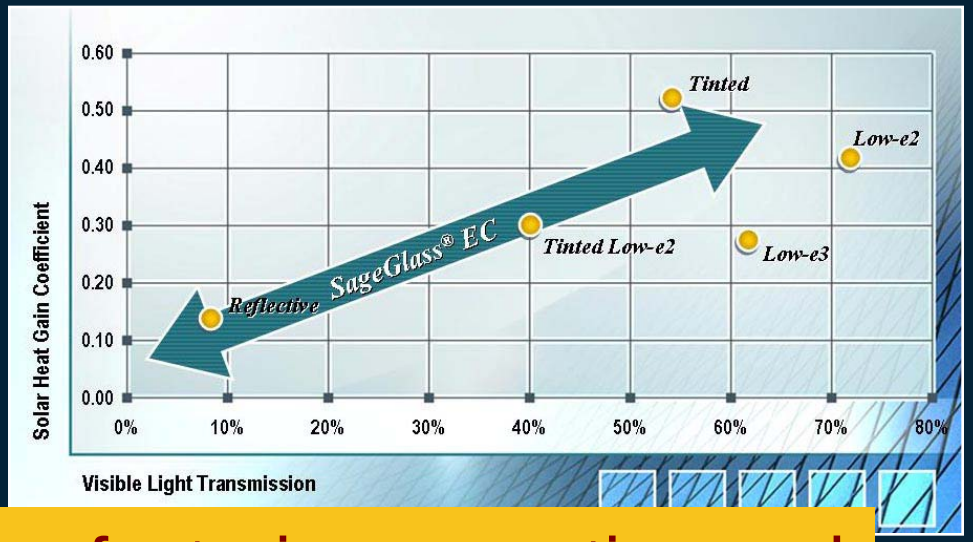
APPLIED MATERIALS®

Large Area Glass Coating Systems

- Glass Substrate is ~ 2.6 m x 3.6 m
  - Uniformity Spec of +/- 1% on 275 nm film (10 layer Triple Low e stack)
- 18 Chamber System ~ 90m: one panel every 20 sec
  - Annual output ~ 10 million m2 (10 km2)

Electrochromic "Smart Glass"





Goal is to bring nanomanufacturing expertise and scale to bring the cost/m^2 from $1000 to <$100-150 range

Market studies indicate opportunity to address over 60% of buildings windows market at that cost point

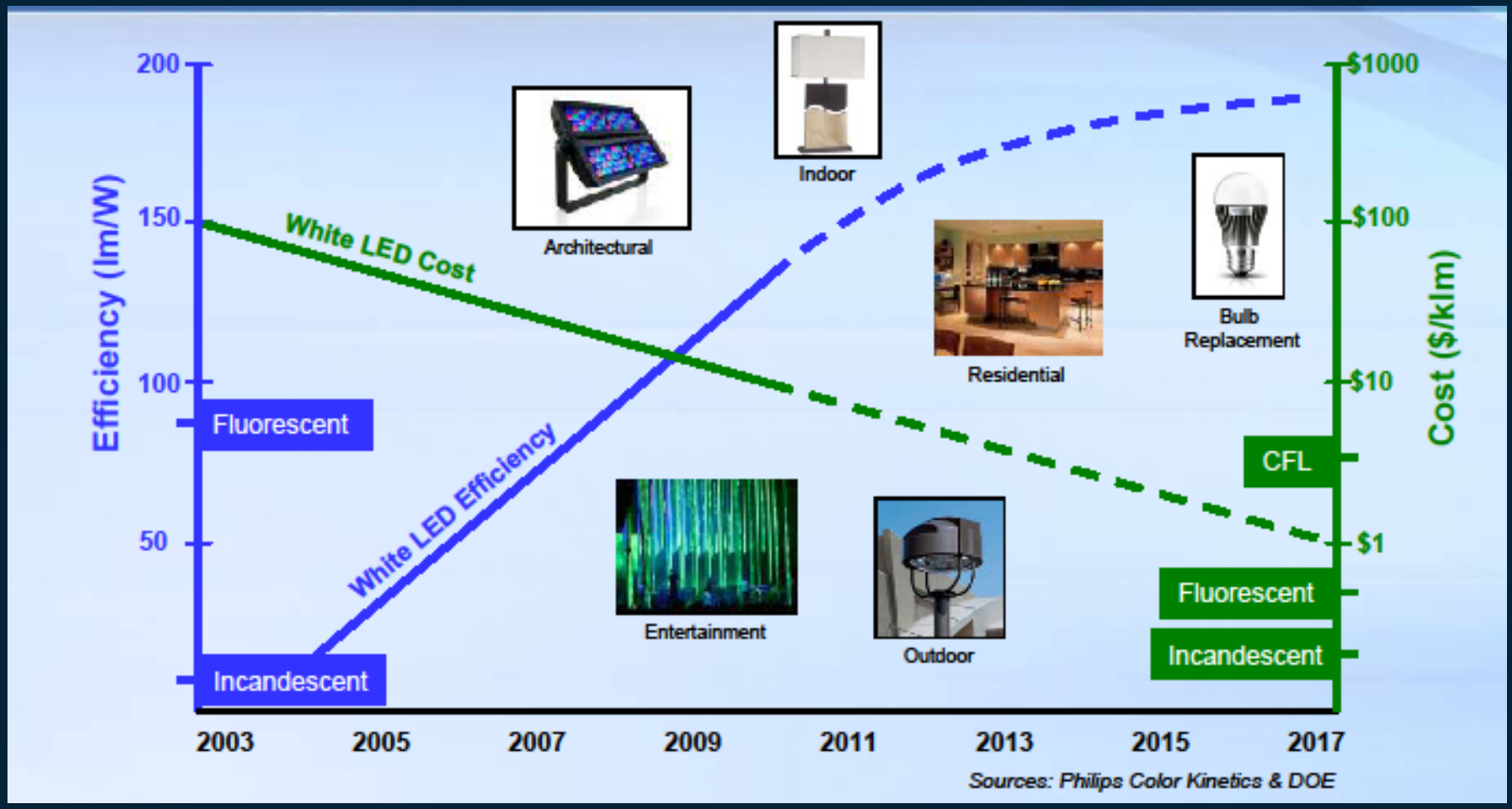
Images courtesy of Sage Electrochromics

LED Industry's Near Term Focus is on Backlight Inflection

LED Backlighting for Laptops and LCD TVs is the Next big thing

- Display Search projects LED backlighting for laptop market to grow from 52% in 2009 to 100% in 2012 driven by: Power savings, Slim form factor & green technology
- All major LCD TV players are investing- e.g. Samsung, Sony, LG
- Attractive attributes
  - High Contrast (3,000,000:1)
  - Lower energy consumption
  - Color Gamut>105%
- LCD TV market is forecasted to grow - 17% CAGR, 200 M sets in 2012
- #LEDs per TV is 900 in 2009- going down to 500 by 2012

General Illumination Opportunity: Cost & Efficiency



Need ~ 10x LED Cost Reduction for General Illumination

Source: DOE, SSL Program

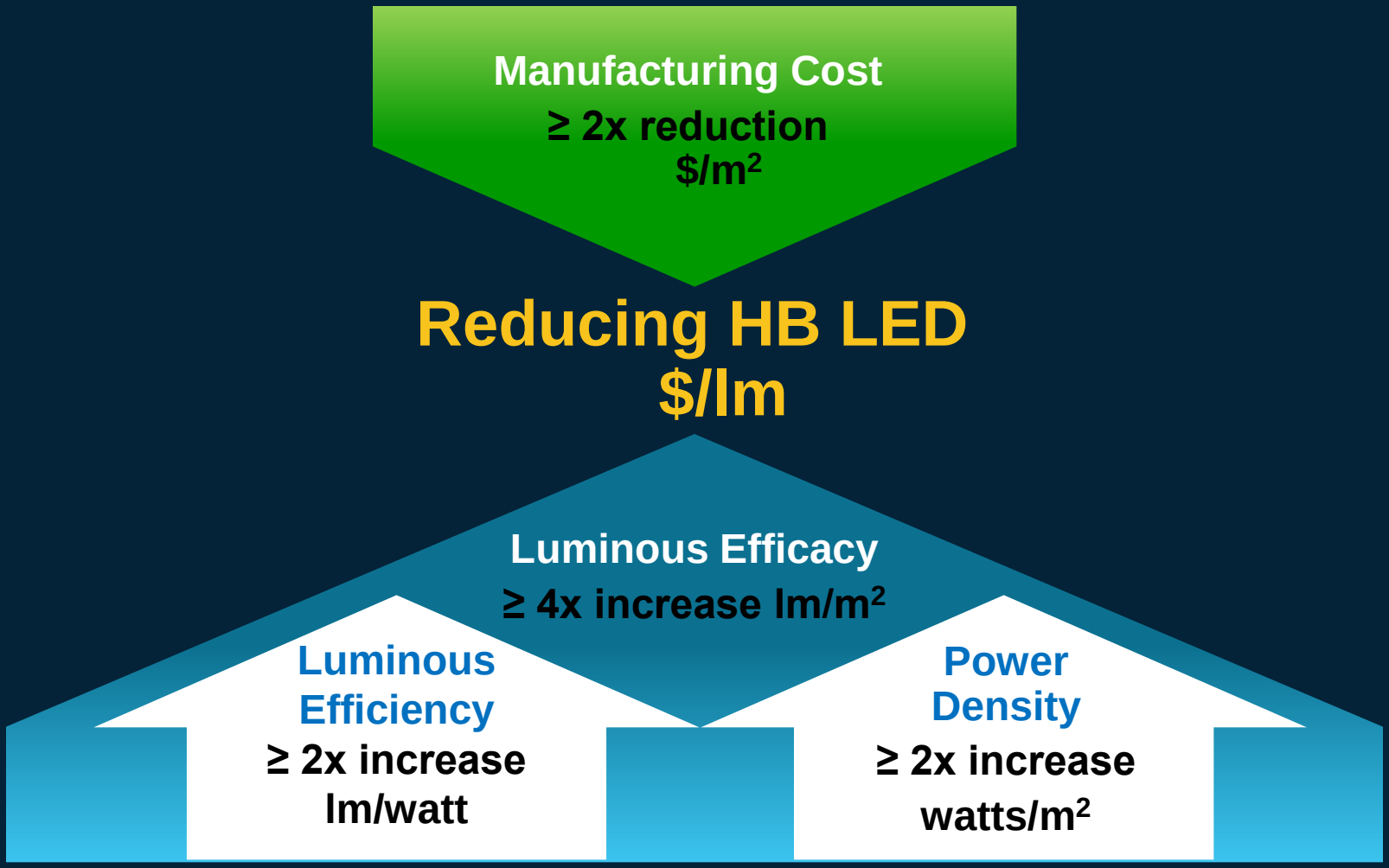
Opportunity in LED Lighting

Efficiency of LED lighting is improving at ~10 lumens/watt

Need 10X LED cost reduction for HBLED general illumination

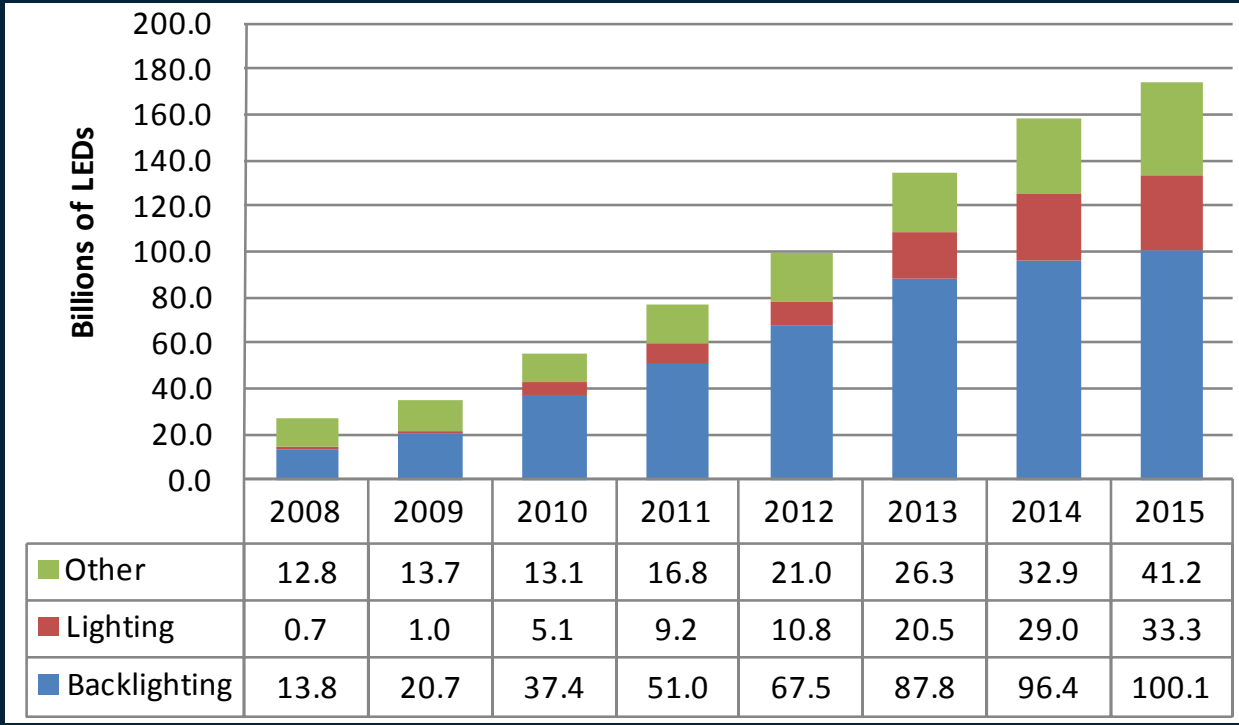
Source: DOE, SSL Program, Applied Materials

Improvements to Reach 10X Cost Reduction



Total LED Demand

- LED demand to grow at a 38% CAGR from 2009 – 2015 to 175B die.
- Backlighting application will continue to dominate
- Lighting to dominate growth at a 102% CAGR



	2008	2009	2010	2011	2012	2013	2014	2015
Other	12.8	13.7	13.1	16.8	21.0	26.3	32.9	41.2
Lighting	0.7	1.0	5.1	9.2	10.8	20.5	29.0	33.3
Backlighting	13.8	20.7	37.4	51.0	67.5	87.8	96.4	100.1

www.ledmarketresearch.com

Solar/PV and the 1970s Energy Crisis

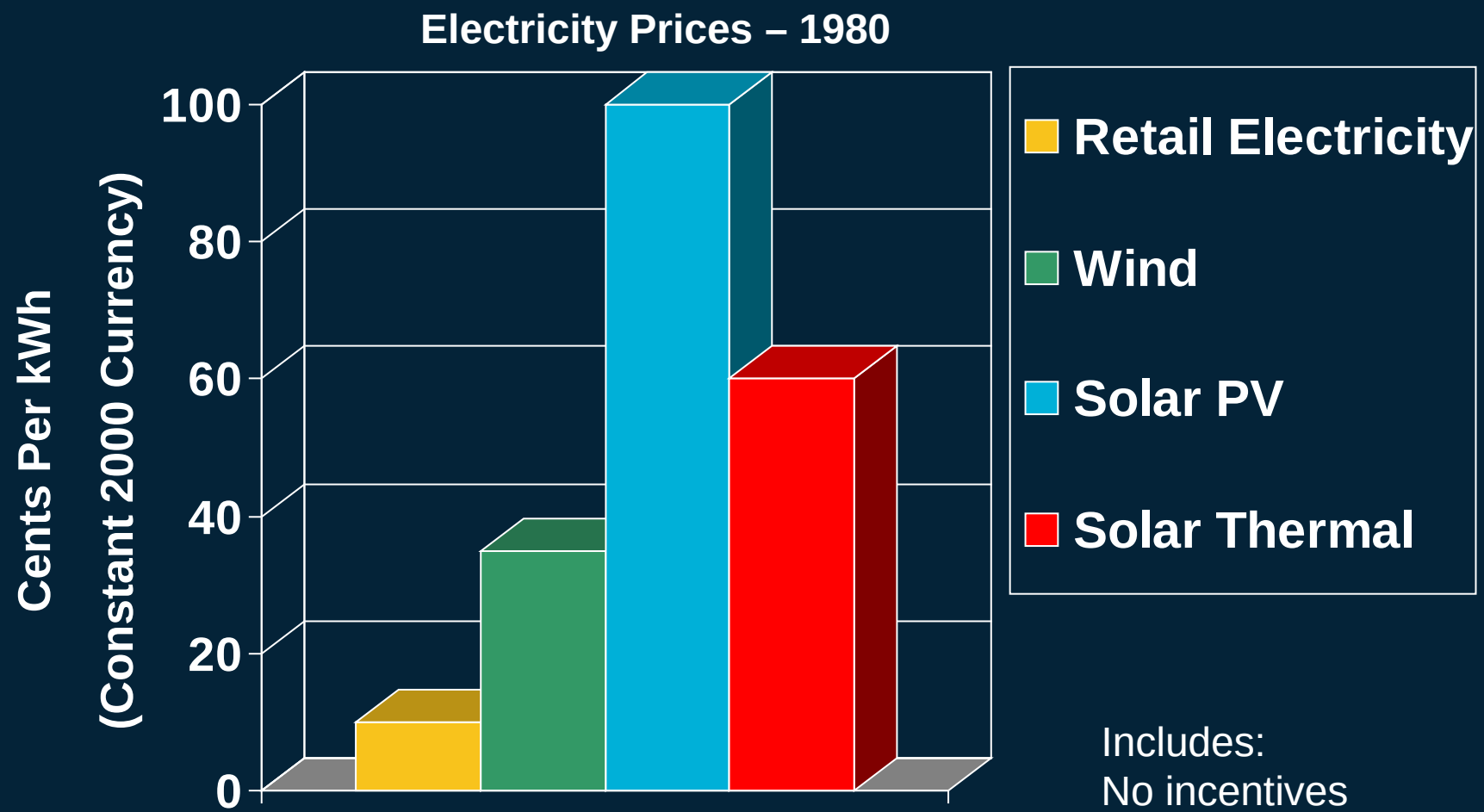
- "I will soon submit legislation to Congress calling for the creation of this Nation's first solar bank, which will help us achieve the crucial goal of 20 percent of our energy coming from solar power by the year 2000." – Jimmy Carter, 1979

White House West Wing - 1984

White House West Wing - 1992

- "The administration has significantly reoriented the country's approach to energy matters in the past 2 years." – Ronald Reagan, 1983

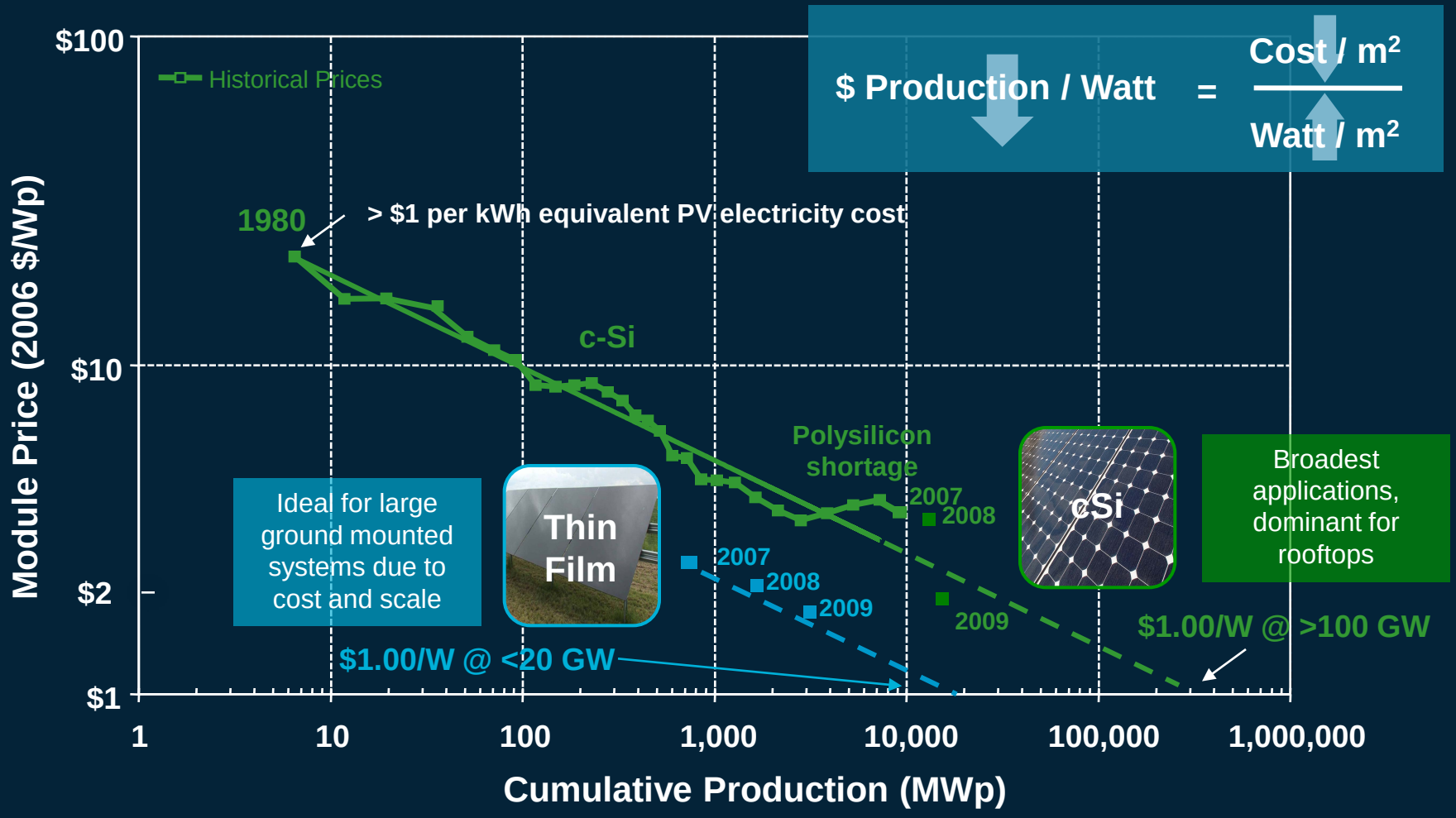
The Problem was the Economics…



Includes:
No incentives
No Carbon impact

Sources: NREL, DOE

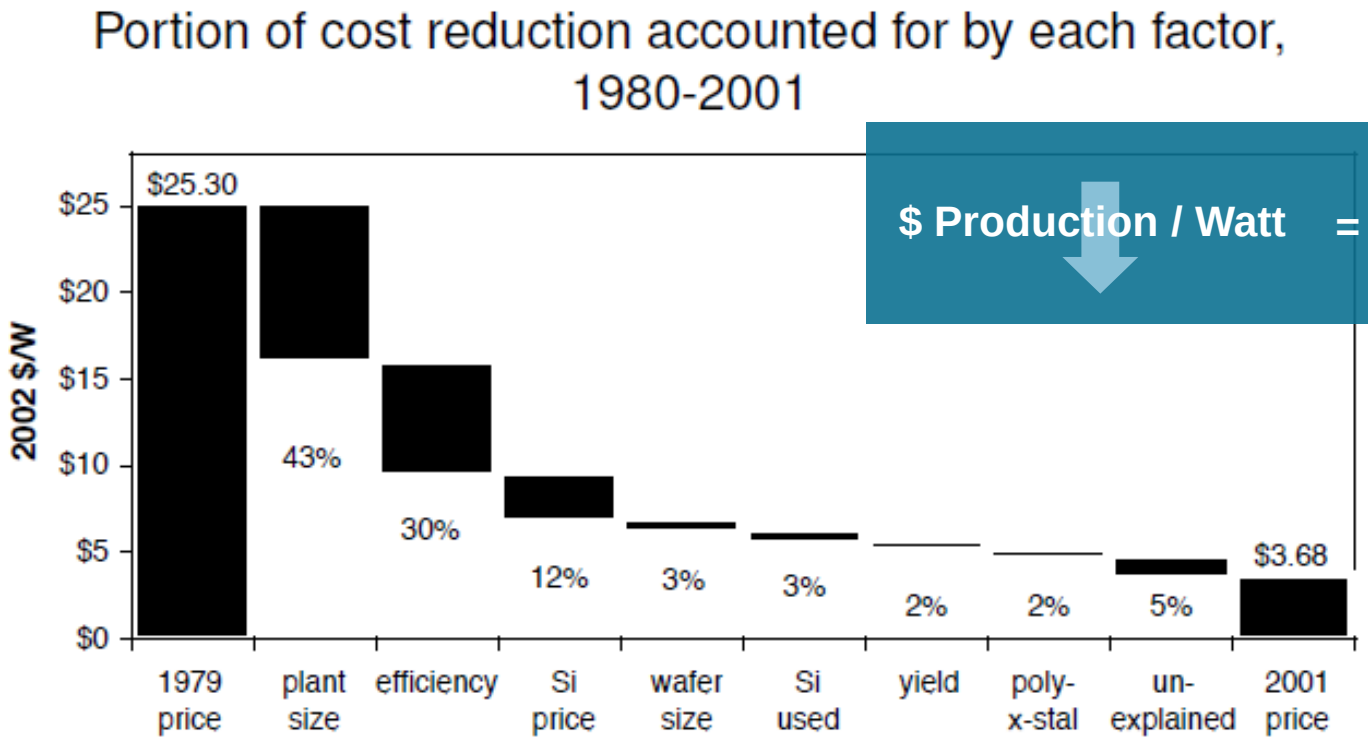
Solar PV Learning Curves: cSi and TF



Common focus to drive down cost per watt

Source: Adapted from National Renewable Energy Laboratory

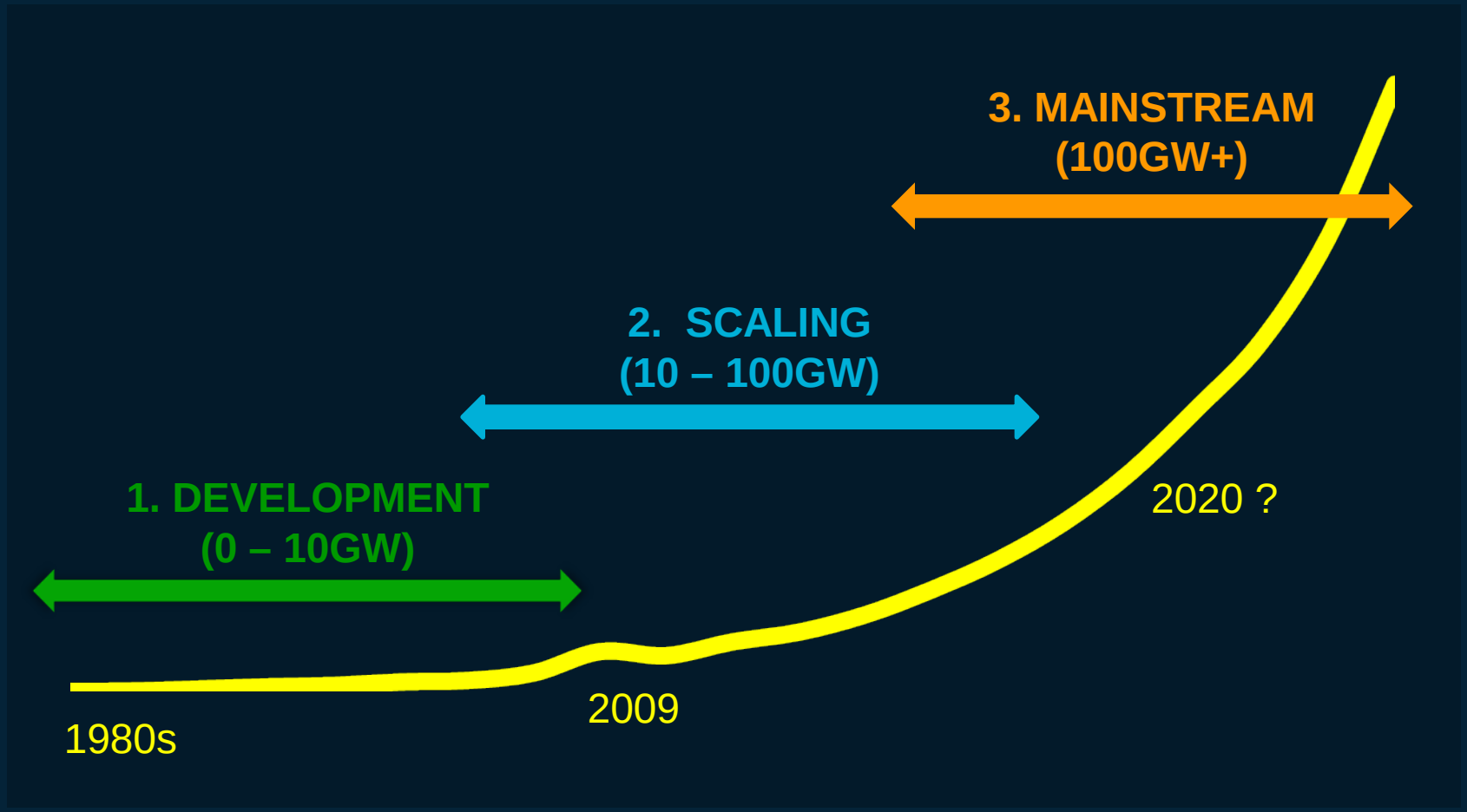
Behind the PV Learning Curve



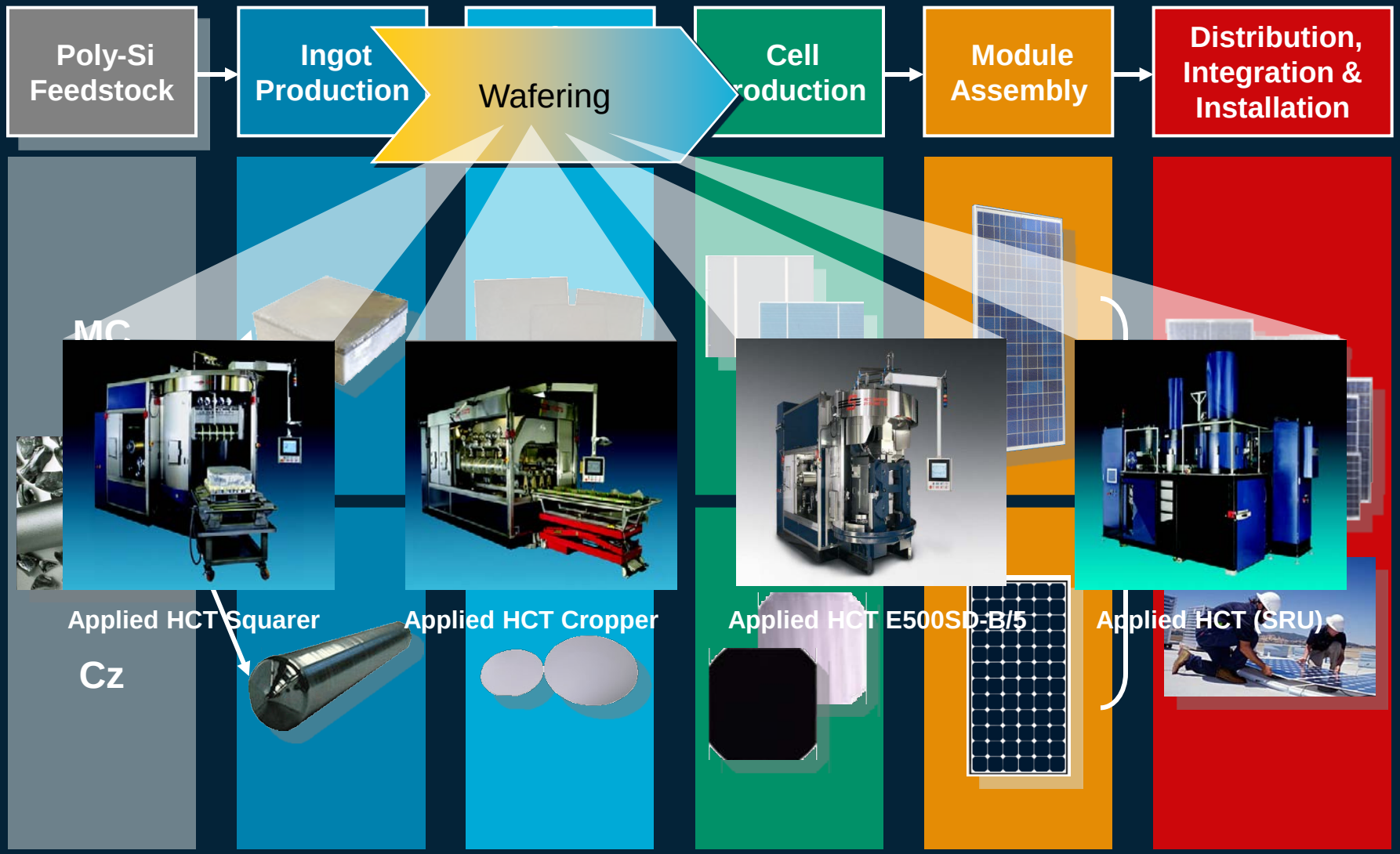
$ Production / Watt = Cost / m^2 ÷ Watt / m^2

Gregory Nemet | Learning Curves for PV | 14

Solar PV to Become Mainstream As it Approaches Grid Parity

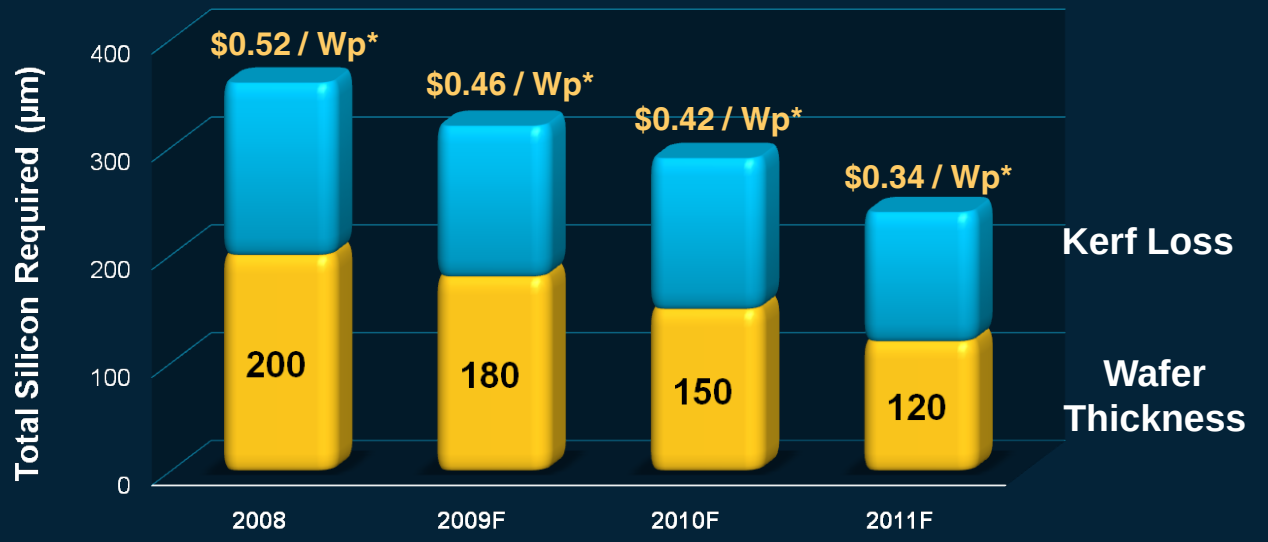


Crystalline Silicon PV Value Chain

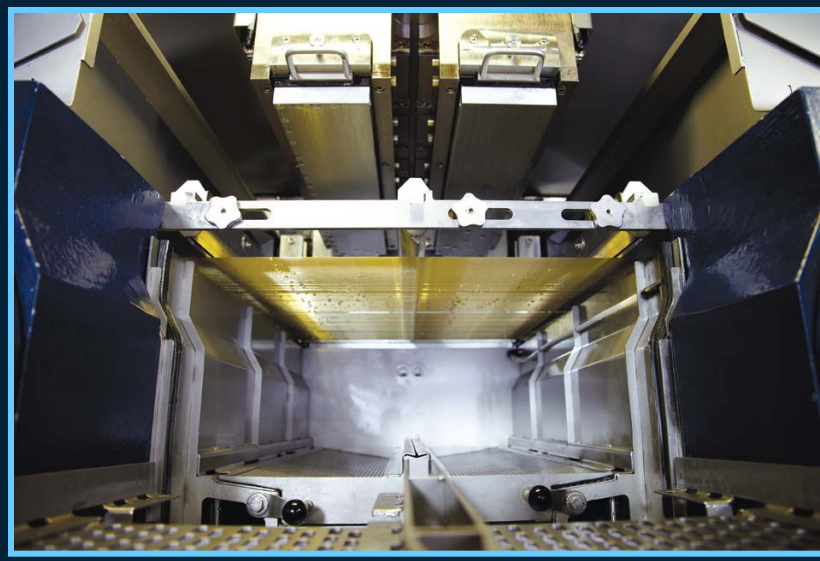


Improve Material Efficiency: Thin Wafers

$$\frac{\text{Cost}}{\text{Watt}} \quad \frac{/\ m^2}{/\ m^2}$$



- 4 ingots concurrently
- Dual wire per motor pair
- 20 m/sec wire speed
- ~ 24K wafers per cut*
- > 13MWp per year



*** Cost assumes fixed silicon costs at $55/kg and constant efficiency**

APPLIED MATERIALS®

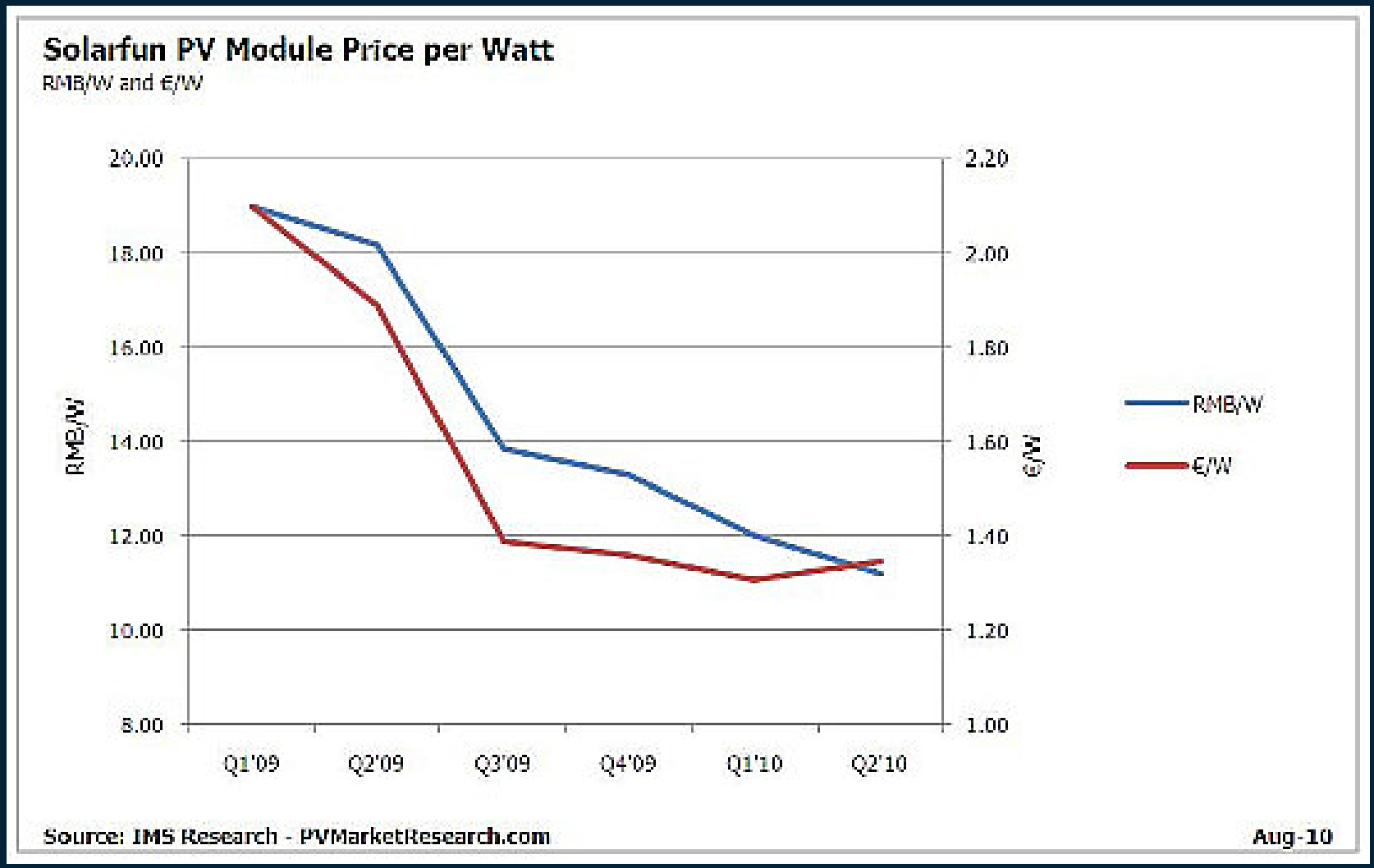
Applied Baccini Cell Systems (BCS)

Polysilicon & Ingot Manufacturing → Wafering → **Cell Manufacturing** → Module Manufacturing

- Ultra-thin wafer processing with low breakage (to 100 um)
- Highest uptime with lowest wafer breakage
- High throughput (1000-3000 wph)
- Excellent alignment repeatability (~10 um)

> 500 Lines Installed
Leading >20% Efficiency Cells Use Baccini Technology

Falling Solar Prices Accelerate Path to Grid Parity



Total Global Installed Capacity ~15GW, New Capacity came on board in 2010 ~12-14 GW

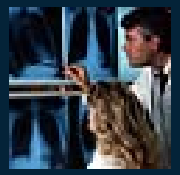
Range of Energy Storage Markets

(Small)

Physical Size

(Large)

Miniature Batteries
(100mWh – 2Wh)
Electric watches, calculators, implanted medical devices



Batteries for Portable Equipment
(2Wh – 100Wh)
Flashlights, toys, power tools, portable radio and TV, mobile phones, camcorders, lap-top computers, memory refreshing, instruments, cordless devices, wireless peripherals

Transportable Batteries (Starting, Lighting & Ignition)
(100Wh – 1,000Wh)
Cars, trucks, buses, lawn mowers, wheel chairs, robots

Large Vehicle Batteries
(1kWh – 1,000kWh)
Trucks, traction, locomotives, regenerative braking

Stationary Batteries
(0.25MWh – 5MWh)
Emergency power, local energy storage, remote relay stations, communication base stations, uninterruptible power supplies (UPS).

Large Energy Storage
(5MWh – 100MWh)
Frequency regulation, Spinning reserve, peak shaving, load leveling

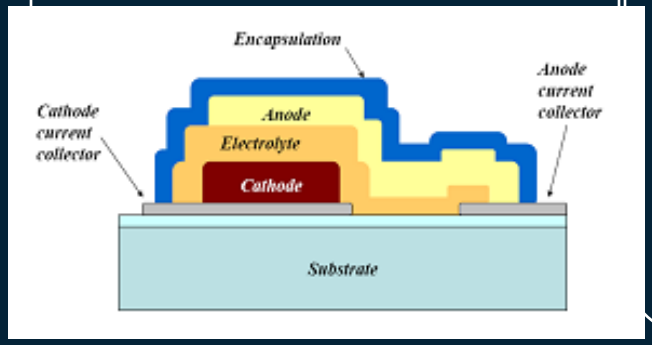
(Low) Energy (High)

APPLIED MATERIALS®

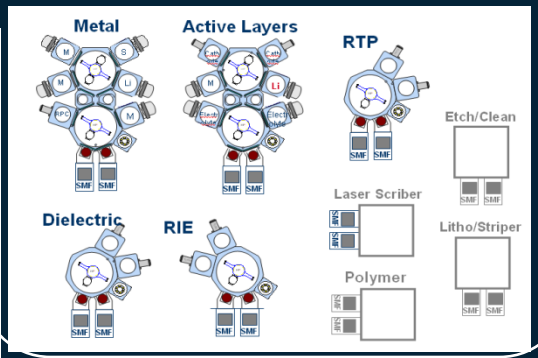
TFB and TFB HVM Technology

- Technology: Potential to dominate μ-energy storage space
  - **Advantages**: Small form factor, excellent cycle and shelf life, power density, safety and solder reflow compatibility
  - **Weaknesses:** Use of shadow masks, thick layers, new materials, complexity with reactive layers
- Applied's Approach : Develop HVM compatible TFB technology:

TFB Schematic Drawing



Si IC Platform



New Aristo Platform

Drive Cost Down to <$1/in^2 with HVM Technology and Scale

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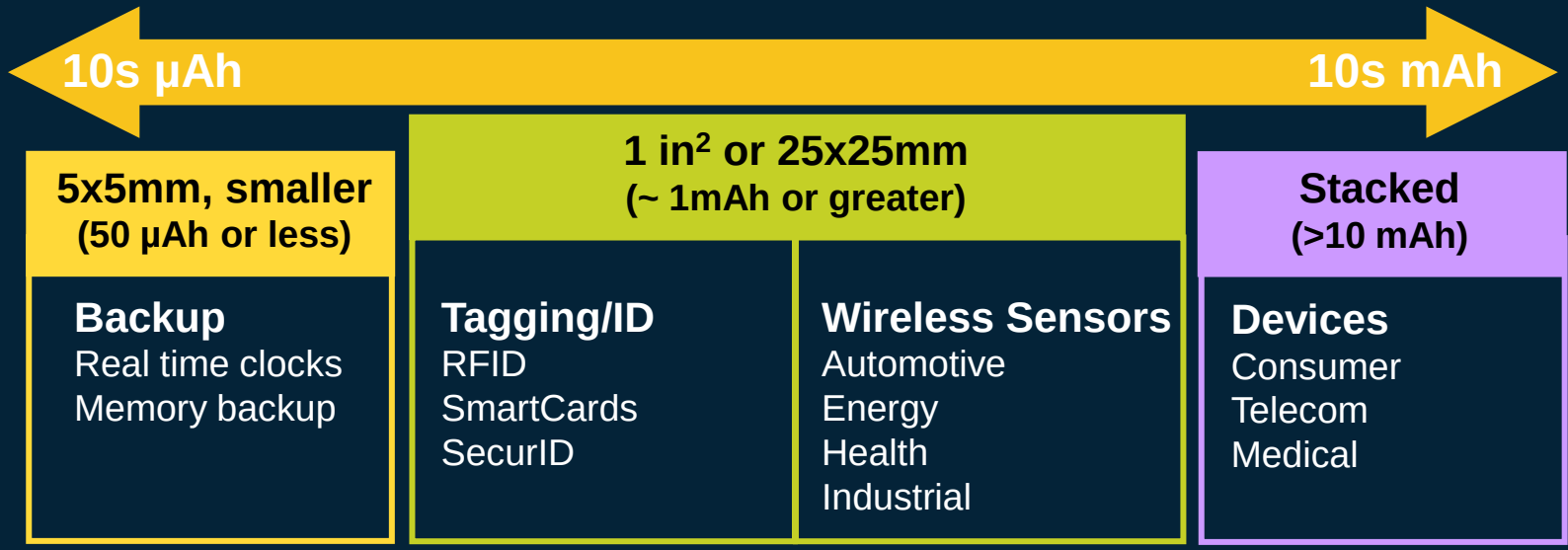
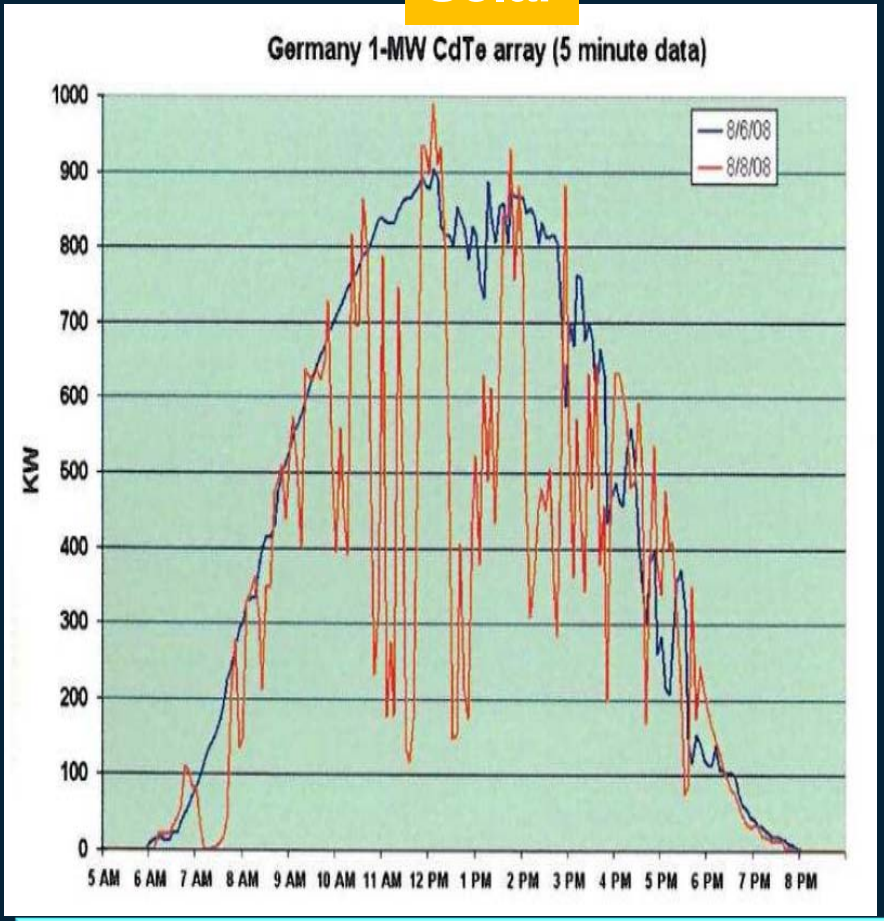
Application areas for TFB

- Robust, rechargeable, micro-sized, solid state battery for μ-power Markets
- Currently projected applications include:

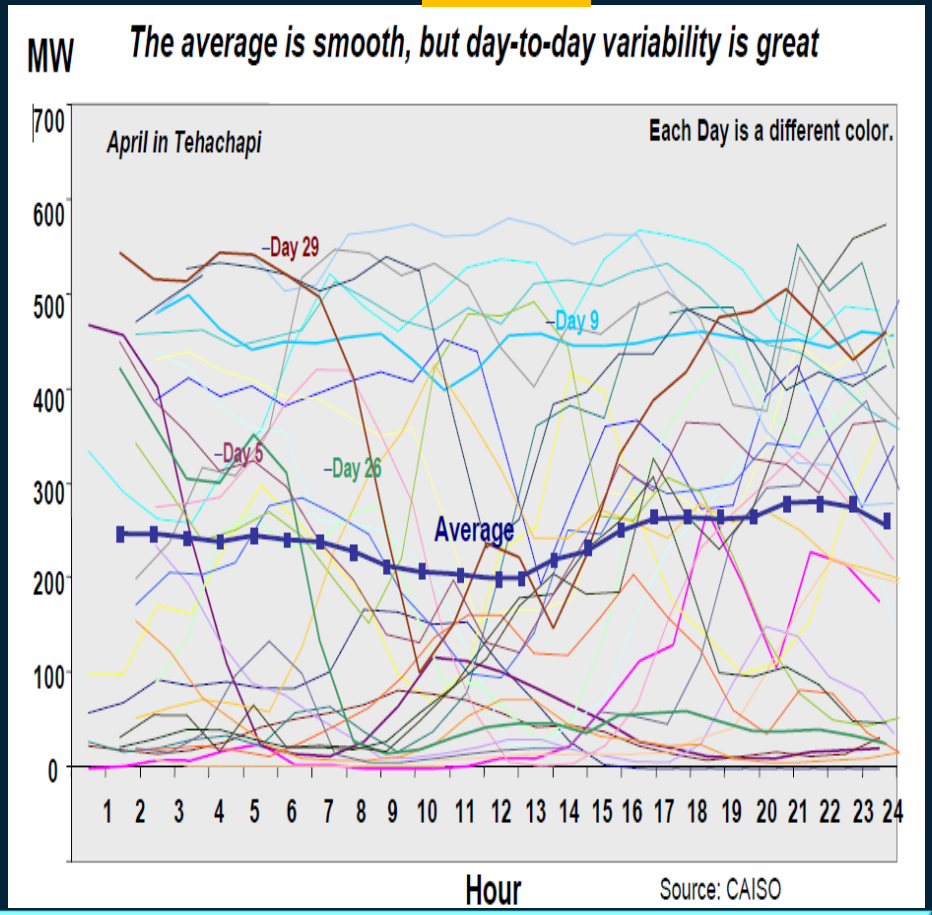


Renewables Intermittency Demands for Grid Storage

Solar



Wind

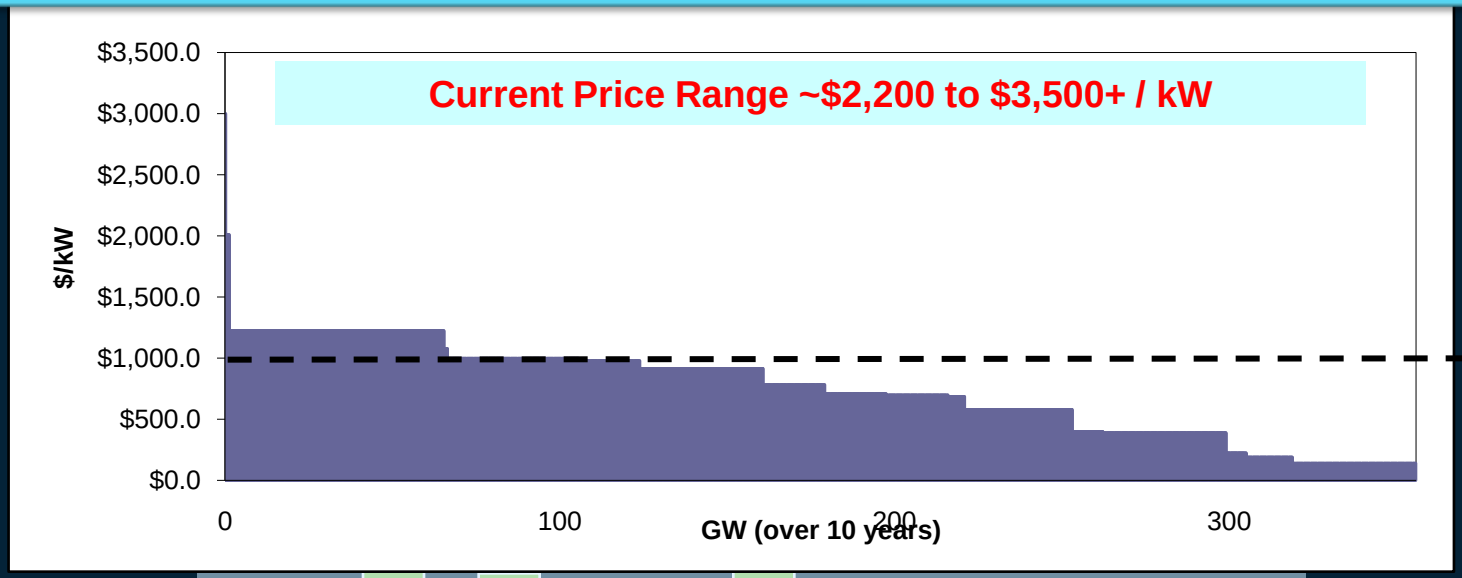


As RPS mandates lead to high renewables penetration, Solar/ Wind intermittency's impact on the grid can be addressed by a Smart Grid with Storage

Grid Storage Market – Economic Benefit Analysis

Energy Storage Business Opportunities are very Price Sensitive – U.S. Market

Pricing below $1,000 / kW & $100-350/kWh System Price enables new markets



Substation On-site Power
Area Regulation
TOU Energy Cost Management Residential only
TOU Energy Cost Management C&I only
T&D Upgrade Deferral (90th Percentile)
Load Following
Wind Generation Grid Integration, Short Dur
Electric Service Reliability
Electric Service Power Quality
Renewables Capacity Firming
Wind Generation Grid Integration, Long Dur
Electric Supply Capacity
Electric Energy Time-shift
T&D Upgrade Deferral 50th Percentile
Demand Charge Management
Voltage Support
Renewables Energy Time-shift
Electric Supply Reserve Capacity
Transmission Support
Transmission Congestion Relief

Source: 2010 Eyer et. al. (Sandia) Energy Storage for the Electricity Grid

Over next 10 years Grid Storage is a $300B Global Market Opportunity but cost per kWh needs to go down from $1000/kWh to ~$100/kWh

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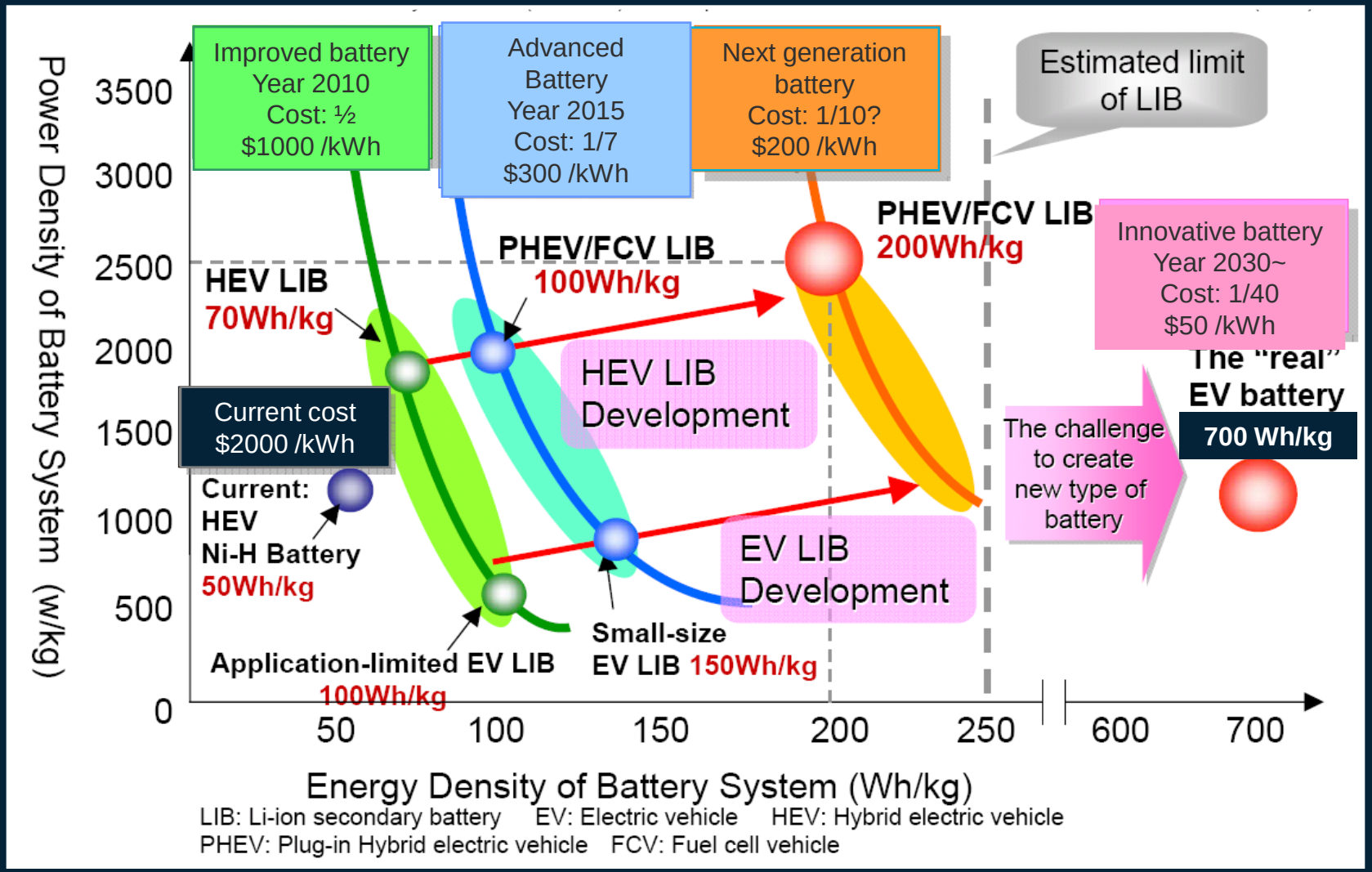
HEV Battery Development Roadmap

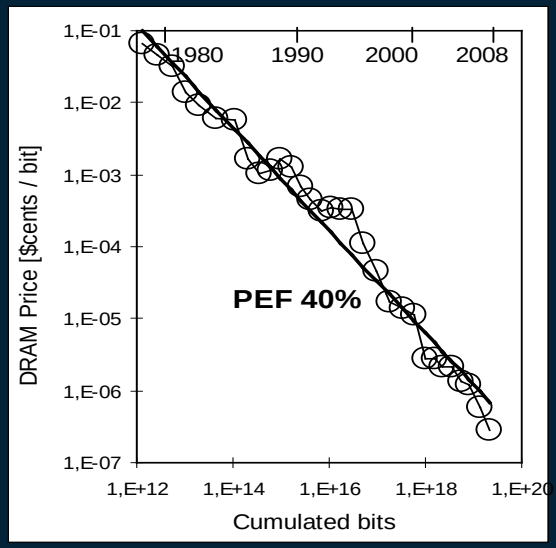


• Source: Iwai Yamamoto, Mitsubishi Chemical Group,GIES Symposium 2008

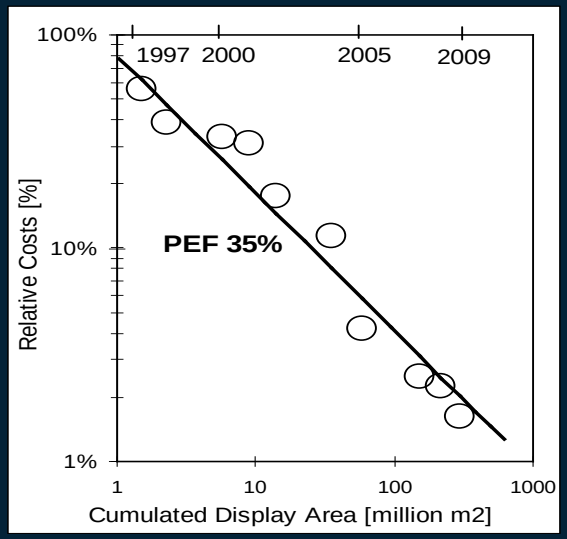
Focus is to Reduce Battery Cost/kWh from $2000 to $300-500 to Enable EV Applications

Applied Materials Enables and Expands Markets by Driving Cost Reduction…. Price Experience Curves

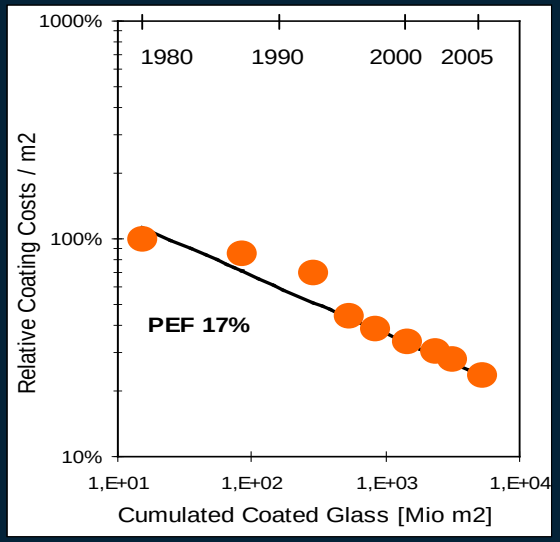
Semiconductors

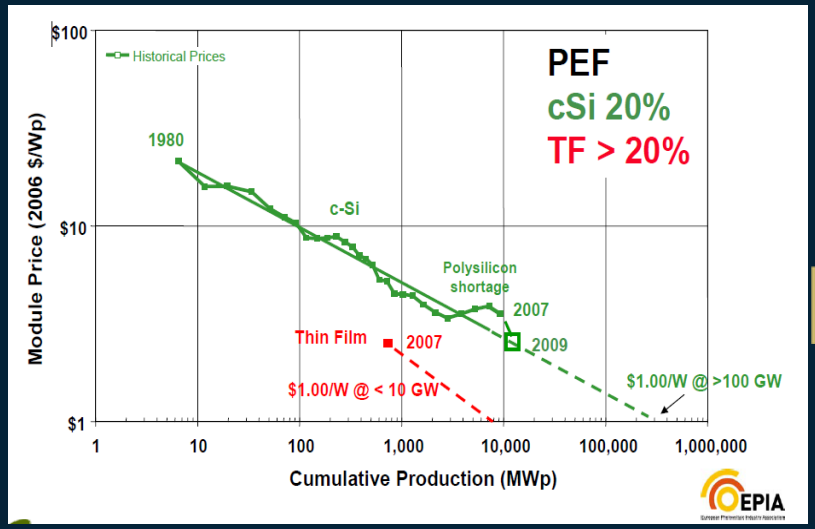


Display



Coated Glass





Solar

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Energy Technology Markets

CAGR '10 – '13F

GENERATION
Solar PV
(~25%)

CONSERVATION
LED
(~24%)

STORAGE
Li-Ion battery
(~20%)

Source: SIA, Display Search, Photon Consulting, Bank of America-Merrill Lynch, IIT Japan, Avicenne, BCC

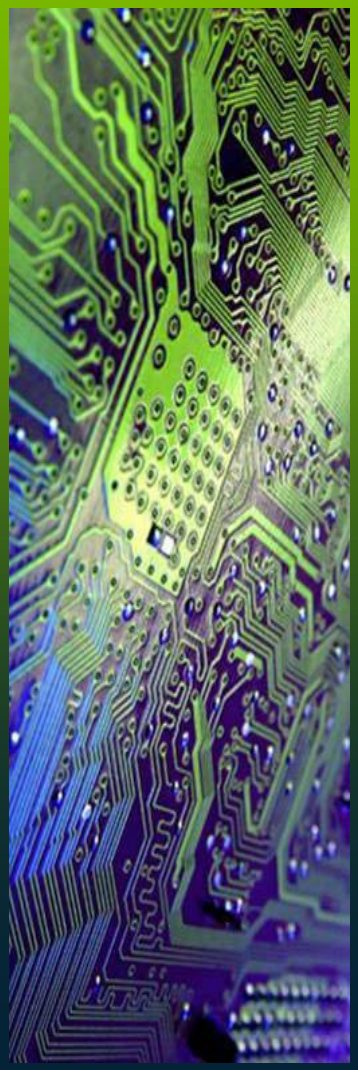
Goal of Extreme Manufacturing Workshop

- How do we translate inventions (world leading science and technology) to innovations (products & services thru manufacturing leadership, jobs and economic development)?
- In Renewables, while manufacturing innovations address cost and performance, policy needs to play a critical role in creating demand and providing a competitive environment for long term investment for job creation

- Call for Action:
  - Policy to foster innovation and economic development
  - Clear targets for direct Investments in US
  - A Comprehensive National RES standard and a roadmap

Summary and Conclusions

- Nanomanufacturing technology is already the foundation of several large markets: Electronics & Display
- Nanomanufacturing technology has the promise to translate the potential of nanotechnology to address the problems of key challenge of our generation: Energy and Environment
- Promising opportunities exist across a number of applications in energy efficiency, generation and storage
  - Glass, LED, PV, Batteries
- Technology and Policy Innovations need to go hand in hand to create a vibrant economy based on Energy and Environment



THANK YOU FOR YOUR ATTENTION