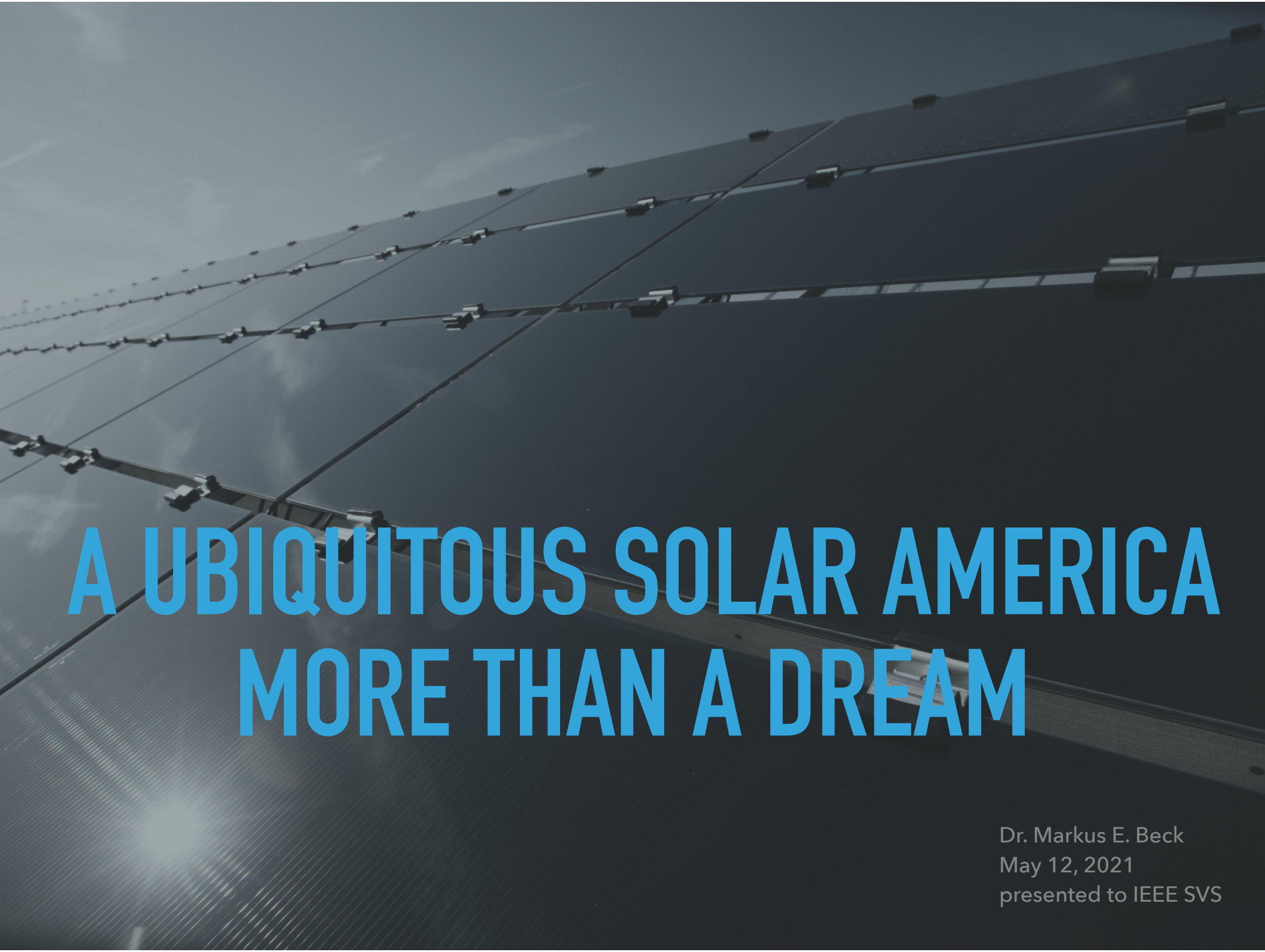
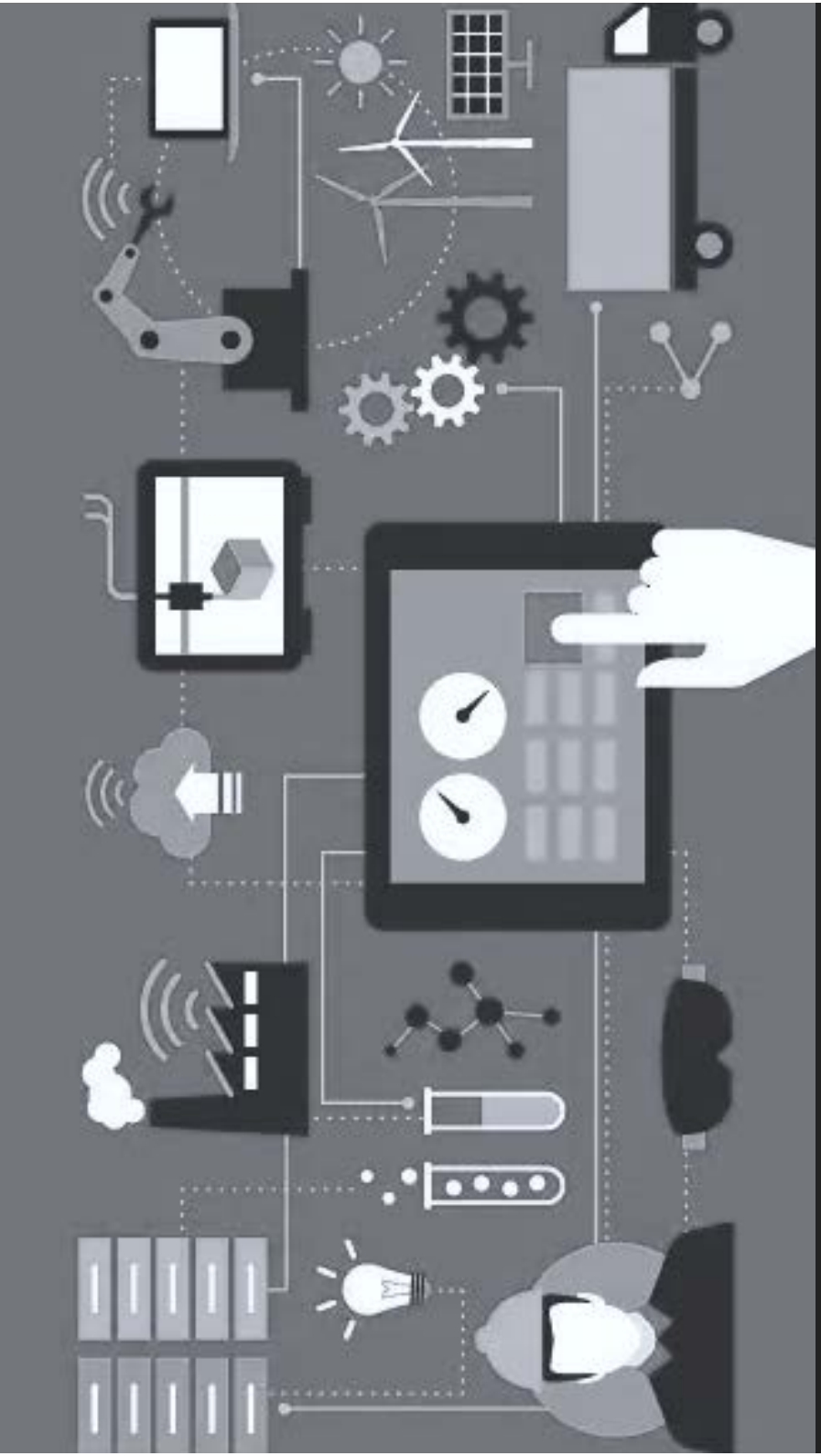


A UBIQUITOUS SOLAR AMERICA MORE THAN A DREAM

Dr. Markus E. Beck
May 12, 2021
presented to IEEE SVS

AGENDA

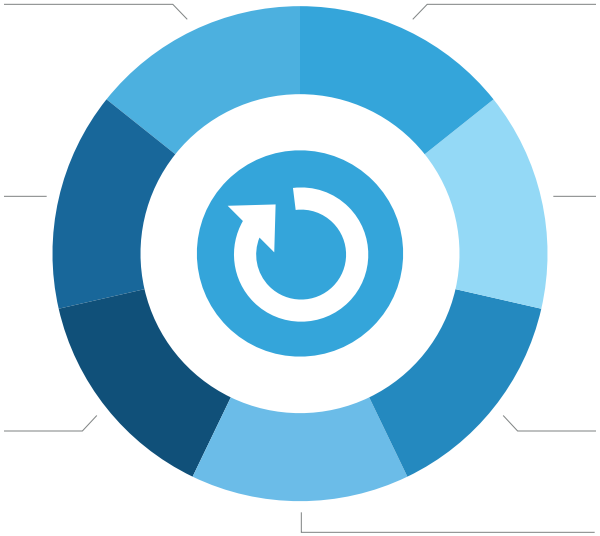
- PV Landscape—a brief Introduction
  - Technologies
  - Markets by Sector & Region
  - Global Manufacturing Supply Chain
- Problem Statement
- The Dream
  - Aspects of Sustainable PV Manufacturing in the US
- Summary—Conclusions & Opportunities



PV LANDSCAPE

PV INDUSTRY

PV LANDSCAPE – INDUSTRY

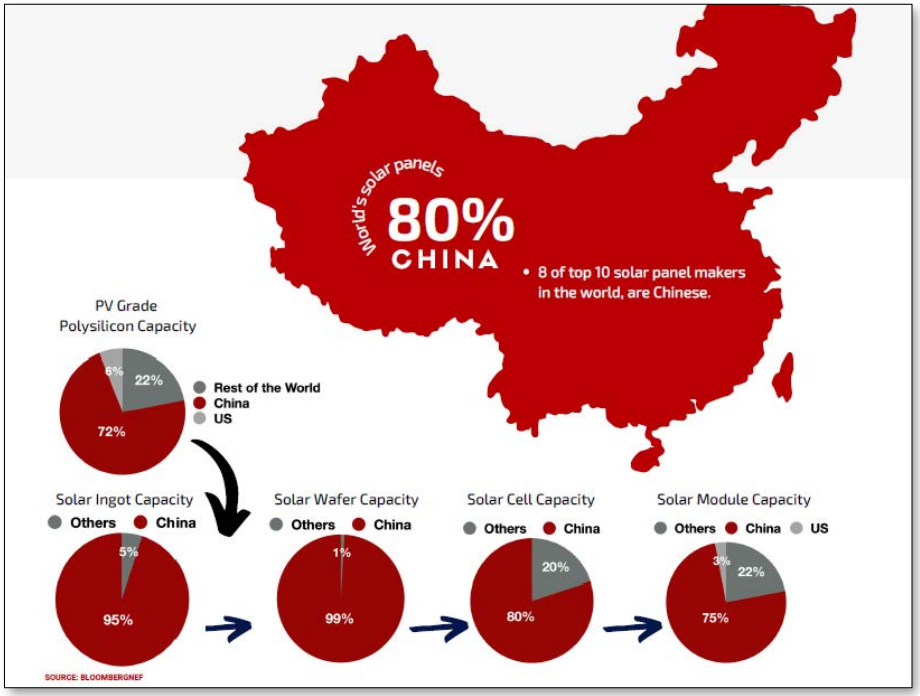


- Diverse
- Inhomogeneous & Fragmented
- Different Levels of Maturity
- Different Interests and Preferences

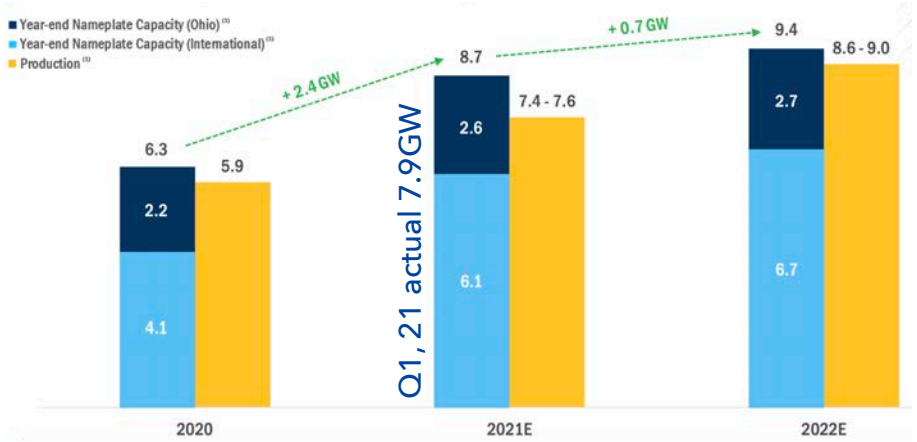
  Talk to focus on Cells & Modules

PV LANDSCAPE – MODULE & PRODUCTION CAPACITY

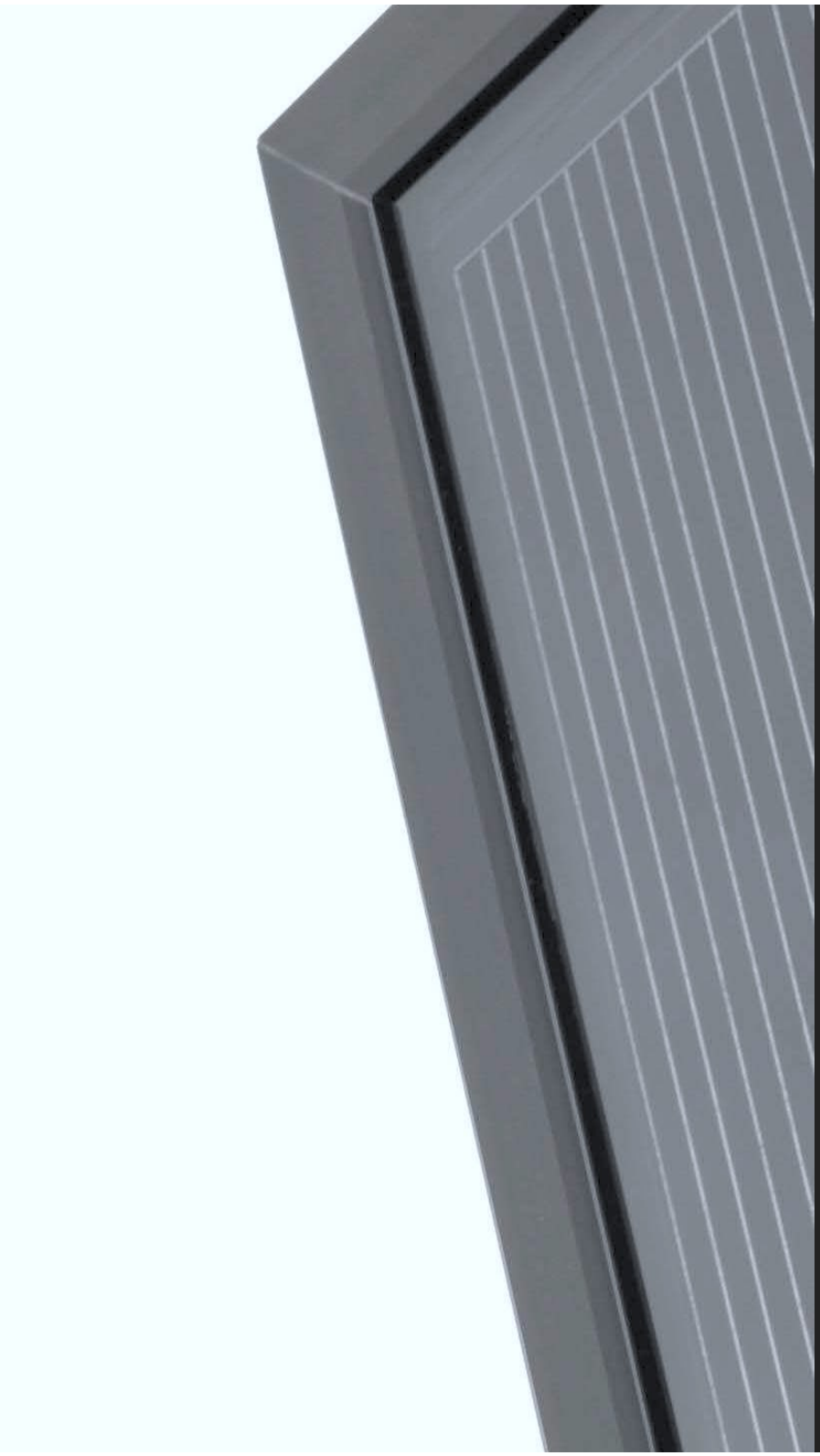
- Global c-Si Capacity ≈ 200–250GW
- China dominates the Production Capacity along the entire Supply Chain
- FSLR Q1'21 global Module Capacity 7.9GW, ⅓ in the US



Source: BNEF



Source: FSLR Q4'20 Earnings Call, February 25, 2021
FSLR Q1'21 Earnings Call, April 29, 2021

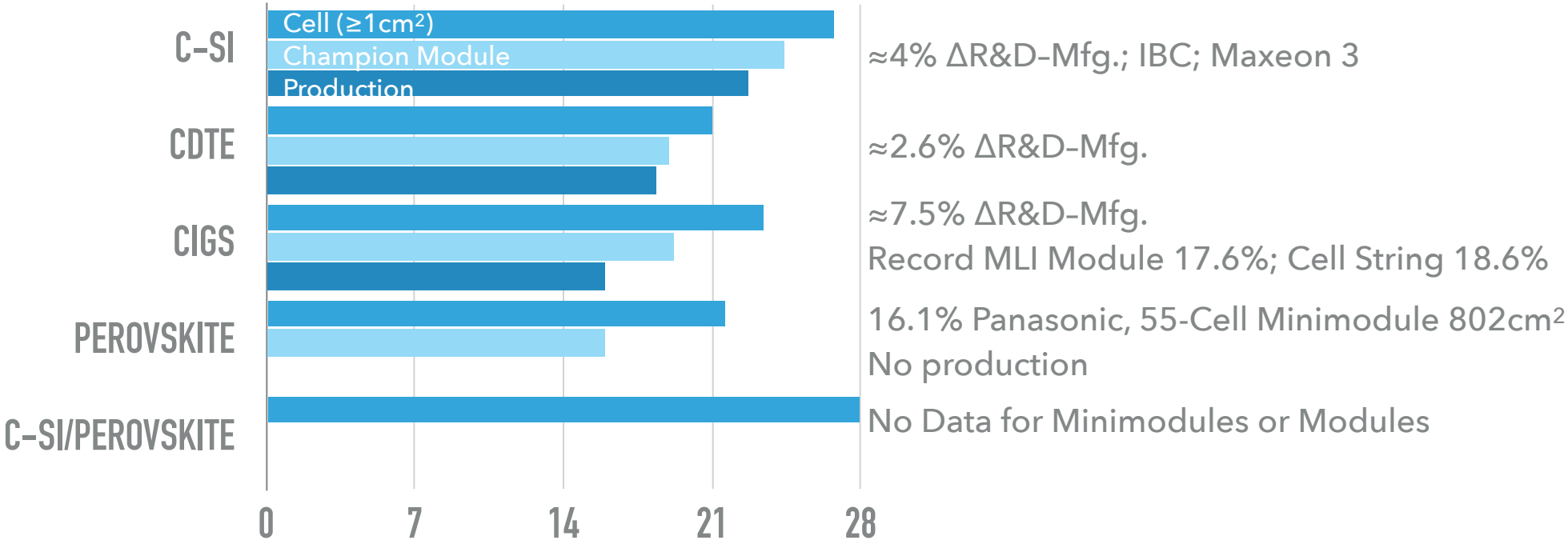


PV LANDSCAPE

TECHNOLOGY

TECHNOLOGY – EFFICIENCY

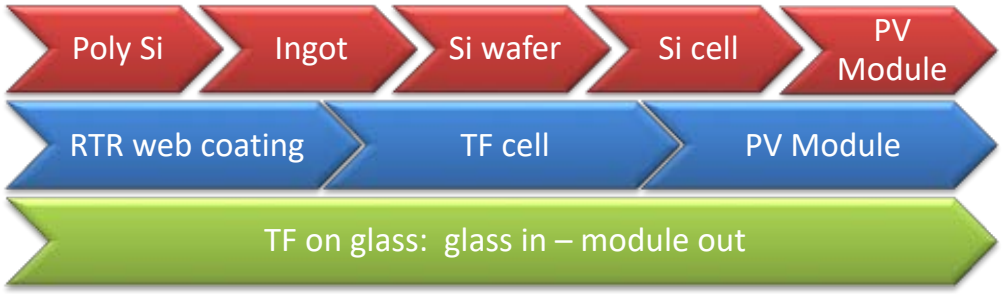
- Smallest Gap R&D-Production for c-Si & CdTe
  - ≈ 2.6-4%
  - Representative for Operational Excellence of c-Si and FSLR
  - CIGS lacking ‚Critical Mass'
  - Perovskites in early scale up Phase—no actual Production
- No other viable next Technology identified



Source: Green et al., *Solar Cell Efficiency Tables (Version 57)*, Progress in Photovoltaics: Research and Applications, 2021; 29:3-15
Manufacturer module data sheets

TECHNOLOGY – MODULE MANUFACTURING

- High Level:



- Module Architecture
  - Glass/Backsheet or Glass/Glass or „flexible“
  - Framed or frameless
  - Various Cell Interconnect Schemes–Ribbons, Shingled, Wire, MLI
  - Mostly EVA & TPO/POE as Encapsulant

PV LANDSCAPE

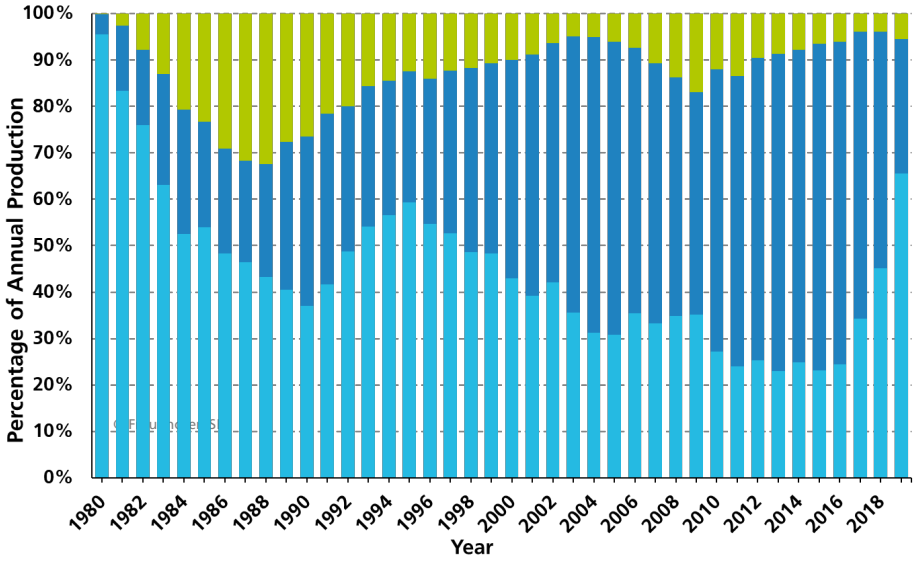
MARKETS

MARKETS

BY SECTOR

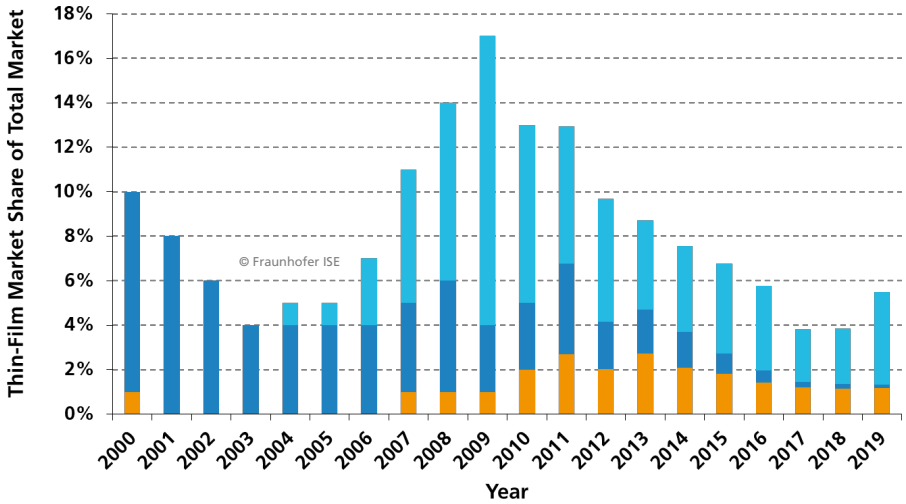
MARKETS – MARKET SHARE BY PV TECHNOLOGY

DESPITE A COST ADVANTAGE COMPARED TO C-SI THE TF PV MARKET SHARE IN THE PAST 5 YEARS HAS BEEN ROUGHLY CONSTANT AT LESS THAN 5%



Production 2019 (GWp)

Thin film	7.5
Multi-Si	39.6
Mono-Si	89.7



Production 2019 (GWp)

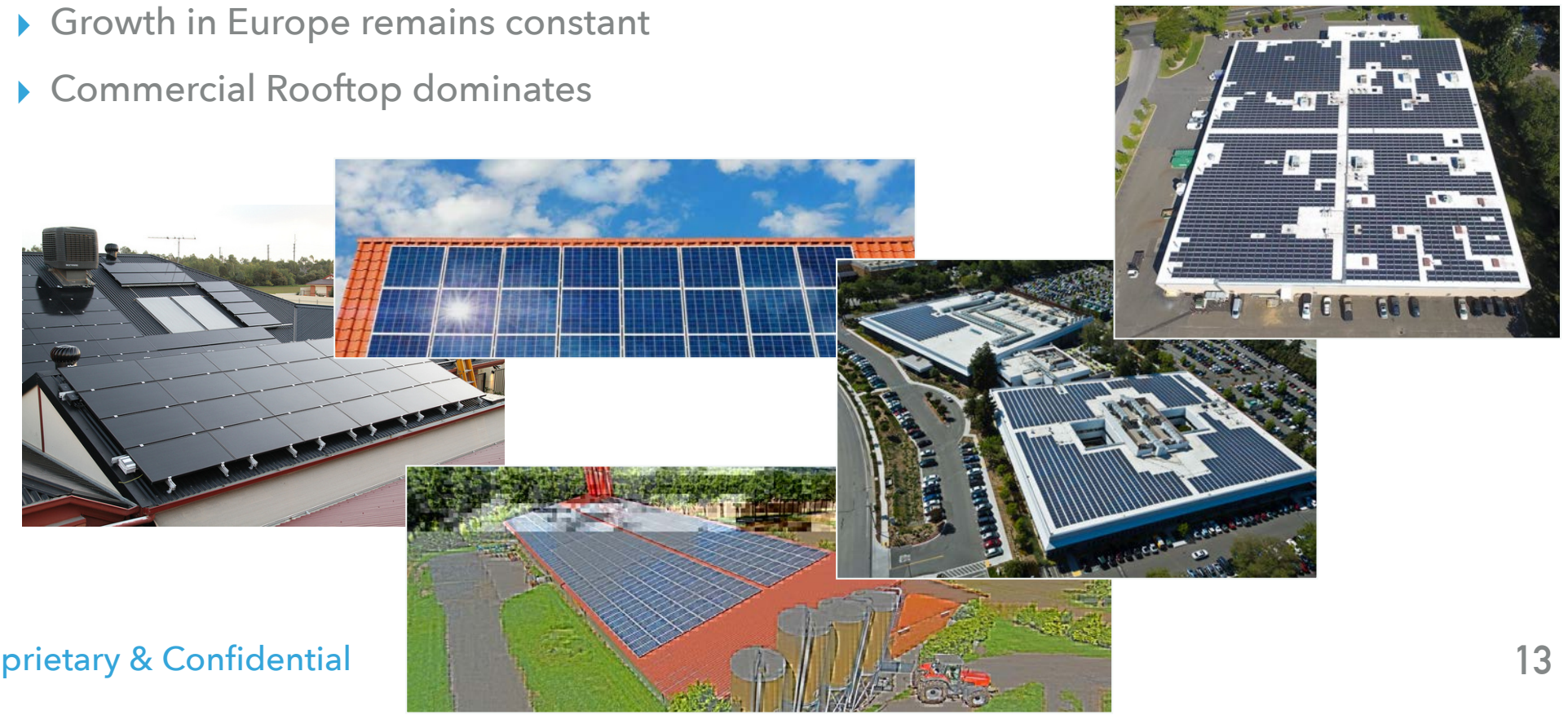
CdTe	5.7
a-Si	0.2
CI(G)S	1.6

Source: Fraunhofer ISE, *Photovoltaics Report*, September 16, 2020

MARKETS — BY APPLICATION — UTILITY-SCALE

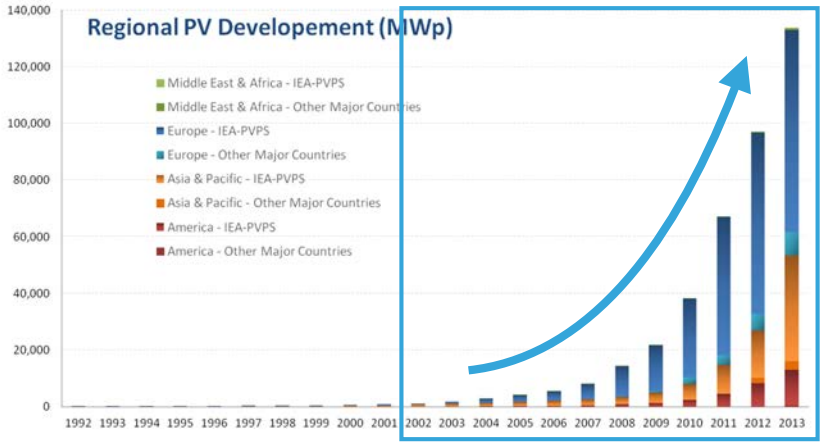
MARKETS – BY APPLICATION – COMMERCIAL, RESIDENTIAL

- Growth in the Rooftop Sector through 2025 is projected at ≈ 11.2% CAGR–as such significantly less than the total Growth of the PV Market (≈ 21-25%)
  - Despite continuously high Soft Costs, the Rooftop Sector in the US is expected to capture almost 40% Market Share
  - The Asia-Pacific Region will account for the highest Growth Rate–most noticeably China and India
  - Growth in Europe remains constant
  - Commercial Rooftop dominates

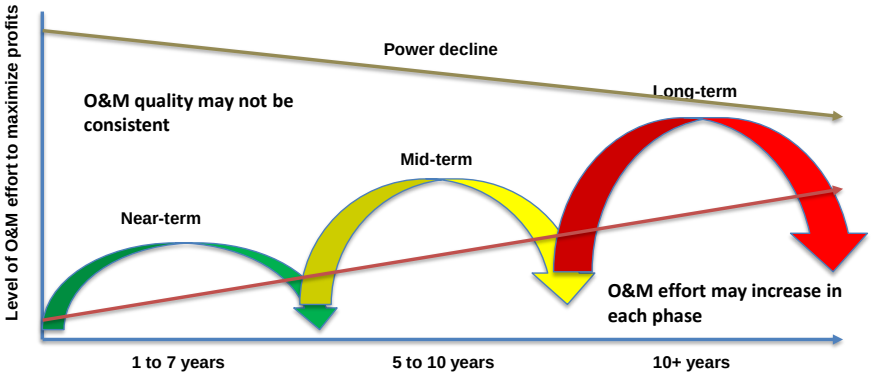


MARKETS – BY APPLICATION – REPLACEMENT (OF OLD) SYSTEMS

- In Europe alone, more than 38GW of the PV Systems at > 100kW are more than 8 Years old–mostly in Germany, Italy, Spain and France
- Module Warranties for these Systems typically 10 Years and many Manufacturers are no longer in Business
- Replacement of failed Module w/wo Warranty
  - Storm Damage (Wind, Snow, Hail)
- Falling Cost of Capital and lower Component Costs offer Incentives to upgrade or replace under performing PV Systems



Quelle: IEA PVPS, 2014

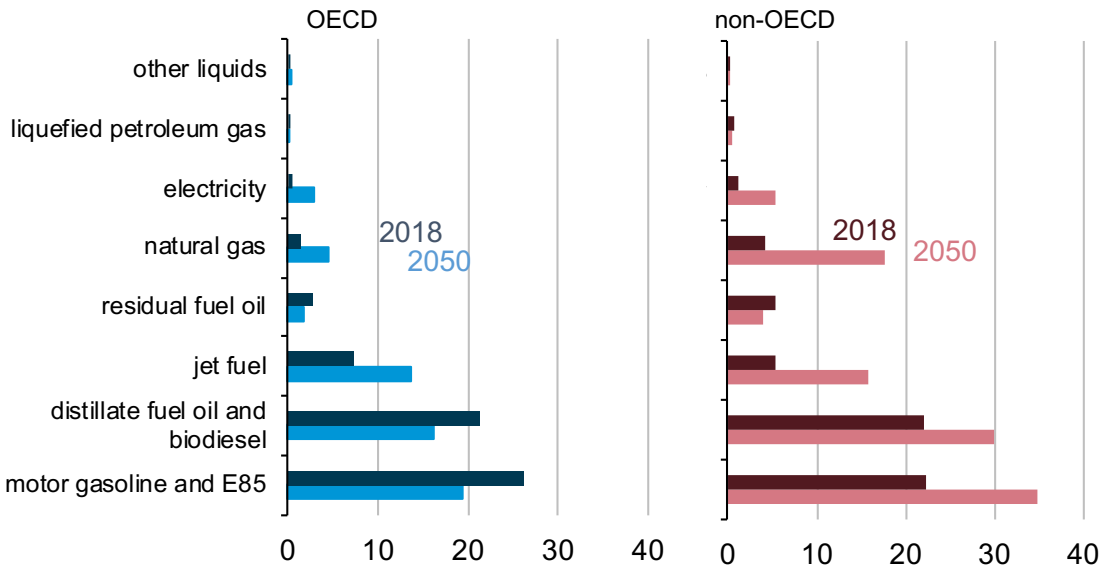


MARKETS — BY APPLICATION — BIPV

MARKETS – BY APPLICATION – VIPV

- Fossil Fuels to dominate Transportation Sector through 2050 according to EIA Forecasts
- Highest Growth Rates of Primary Energy Sources for Gas and Electricity
  - Four-fold Rise in Consumption between 2018 and 2050
- Electric Delivery Vehicles and Cars Development 2018–2050
  - OECD Countries: 3.5 millions → 169 millions
  - Non-OECD Countries: 2.2 millions → 269 millions

Transportation Fuel Consumption in quadrillion Btu



Source: EIA, *International Energy Outlook 2019*, September 24, 2019

MARKETS – BY APPLICATION – MISCELLANEOUS

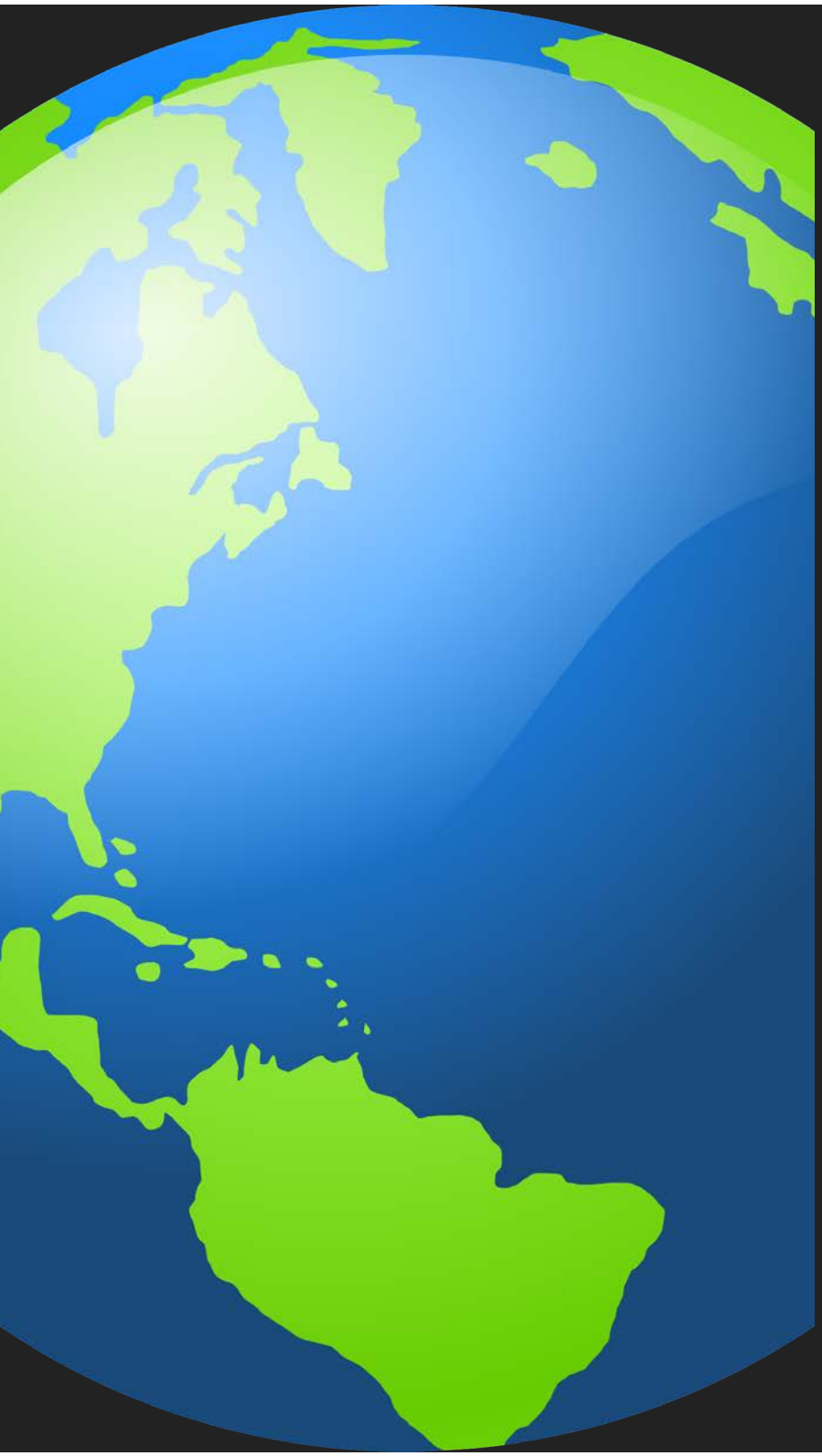
- Niche Markets representative of either low Volumes and high Margins or high Volumes and low Margins
- Military–e.g. Tent Membranes, foldable Modules and Power Packs, UAVs etc.
- Telecommunication–e.g. HALE
- Disaster Response–e.g. Backup Power, particularly robust Modules and Systems
- Consumer Products–e.g. IoT, Drones, Solar Lights, Backpacks etc.
- Sensors–e.g. remote sensing Systems for Indoor or Outdoor Applications









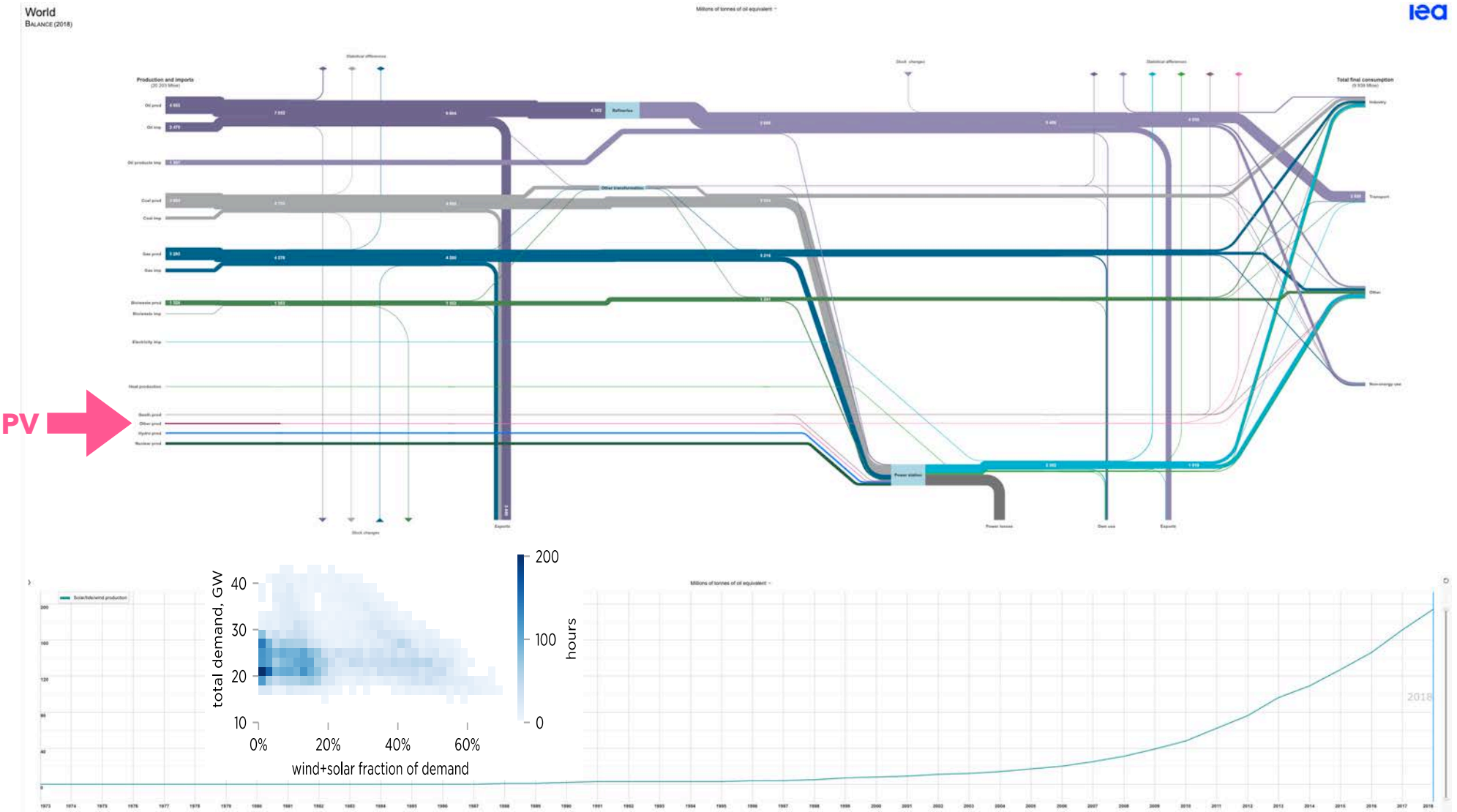


MARKETS

BY REGION

MARKETS – PV'S ROLE IN THE GLOBAL ENERGY MARKET

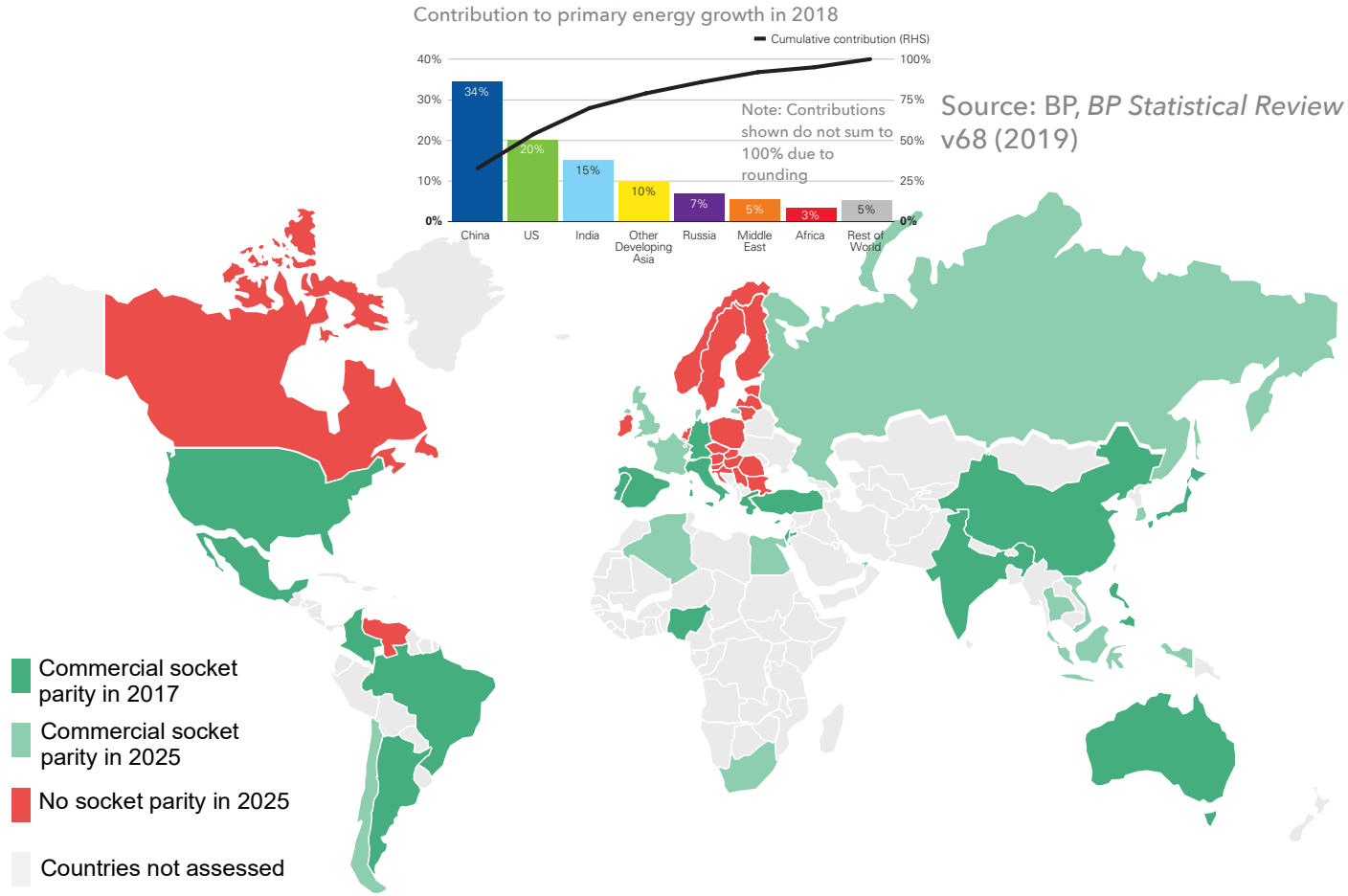
2018 WORLD ENERGY MIX; PV MARKET SHARE ≈ 0.96%



Source: IEA 2021, https://www.iea.org/Sankey/

MARKETS – GRID PARITY

PV HAS REACHED GRID PARITY IN MOST OF THE KEY ECONOMIC REGIONS



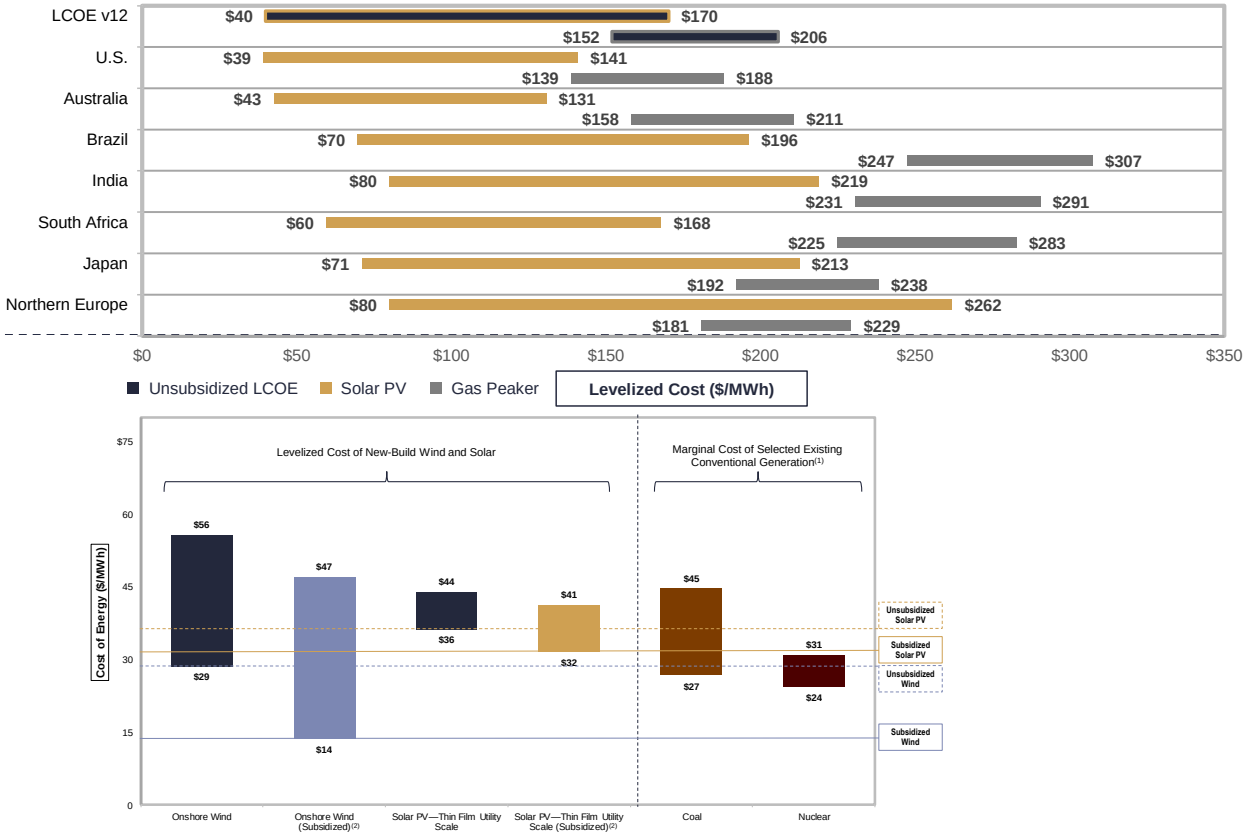
Source: BP, *BP Statistical Review of World Energy*, v68 (2019)

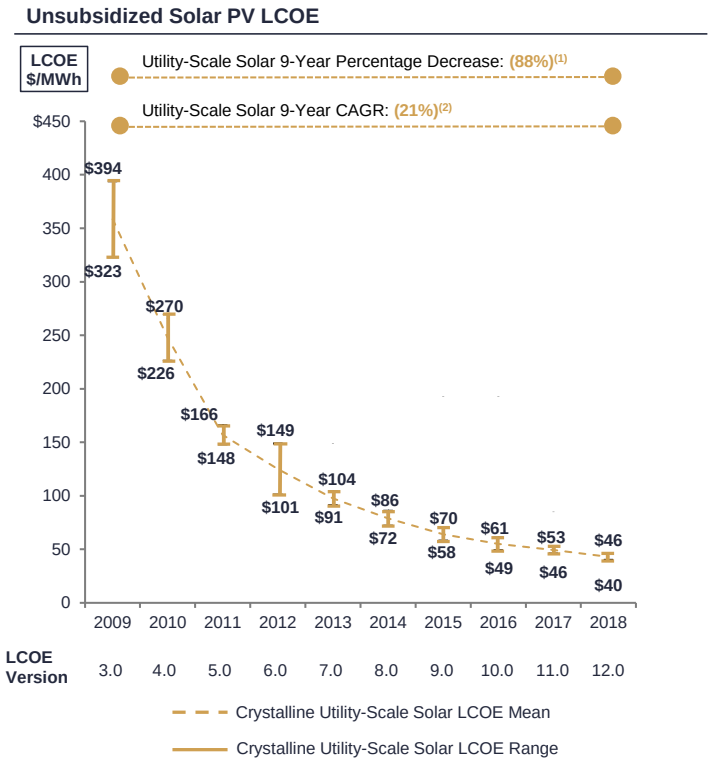
Commercial (behind the meter) PV grid parity in 2017 and 2025 with 75% on-site consumption. Generation-based subsidies (in terms of $/kWh) are excluded.

Source: Wang & Barnett, *The Evolving Value of Photovoltaic Module Efficiency*, Applied Sciences, 9 (2019)

MARKETS – LCOE

- PV competitive even compared to depreciated Coal-fired Generation Assets
- Continued Cost Reduction over the past Decade coupled with Increased Efficiency and lower Cost of Capital resulted in a 10x Drop of PV LCOE

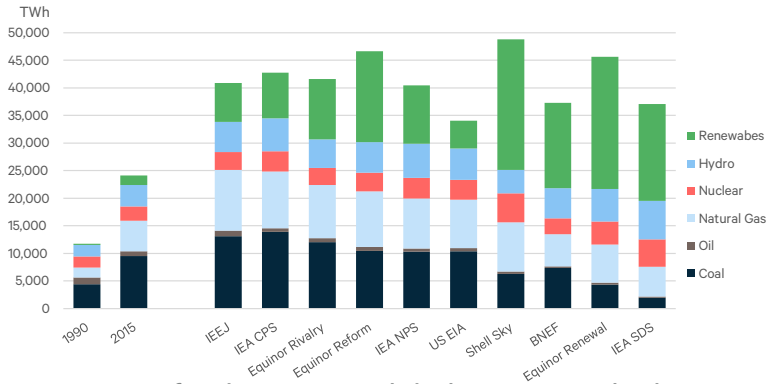




Source: Lazard, *Lazard's Levelized Cost of Energy Analysis*, v12, November 2018

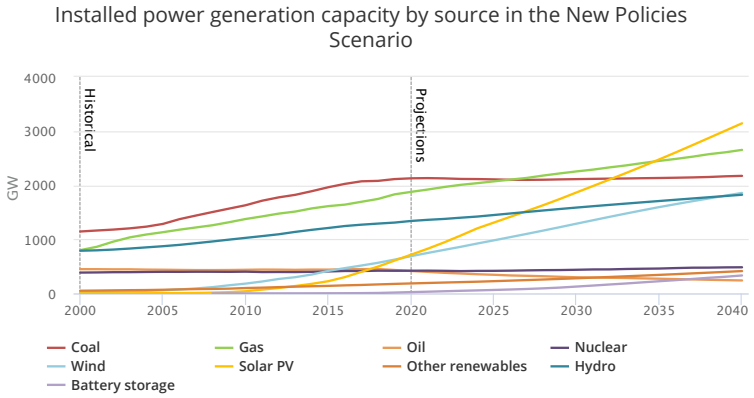
MARKETS – WORLD ENERGY FORECAST

GLOBAL ELECTRICITY DEMAND GROWING AT TWICE THE RATE OF ENERGY DEMAND



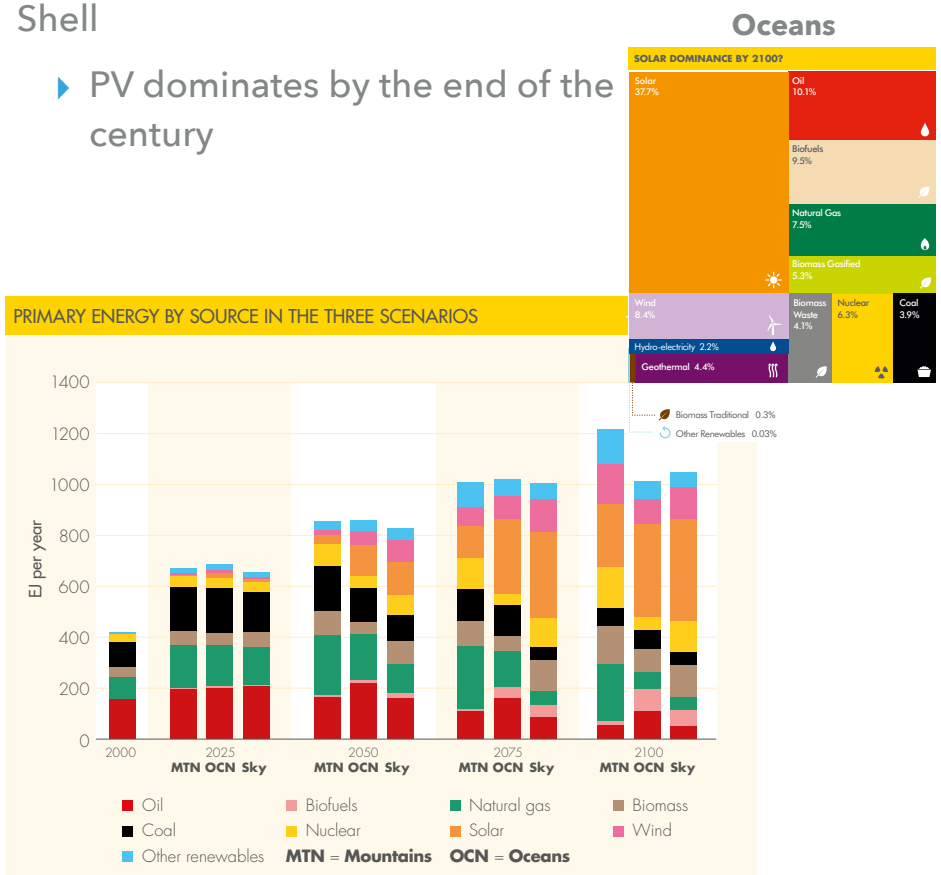
Source: Resources for the Future, *Global Energy Outlook*, August 22, 2019

- IEA
  - PV currently < 1%; ≈ 7.5–10% (2030) resp. 12–20% (2040)
  - PV expected to be largest primary source of energy by 2035



Source: IEA, *World Energy Outlook*, November 13, 2019

- Shell
  - PV dominates by the end of the century

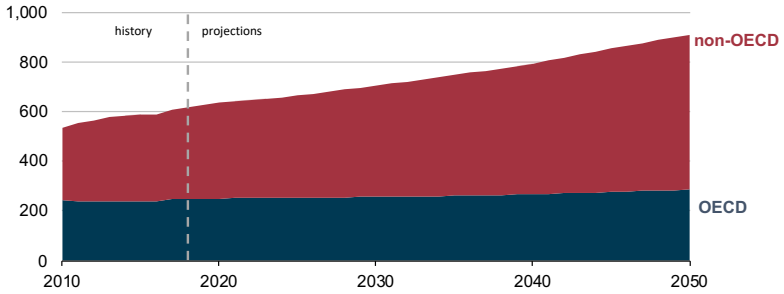


Source: Shell, *New Lens Scenarios*, March 2013 & *Scenarios Sky*, March 2018

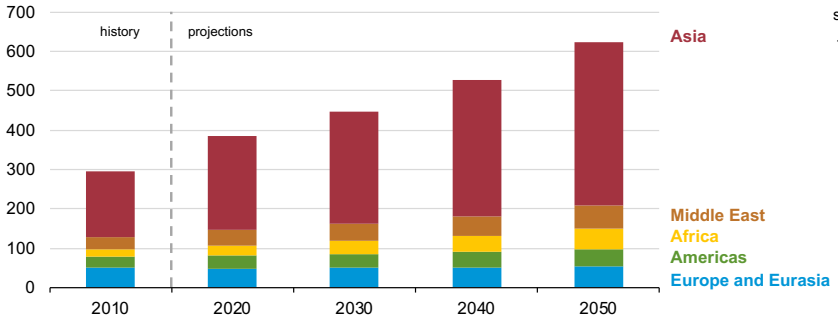
MARKETS – WORLD ENERGY FORECAST

- Global Energy Demand is expected to grow by 50% between 2018–2050
  - Strong Economic Growth and Population Growth in non-OECD Countries–almost 70% Growth
  - Slow Economic Growth and Population Growth coupled with increasing Energy Efficiency and a Decline in Energy Intensive Industries in OECD Member States results in a declining Energy Demand–approx. 15% Growth
- Among non-OECD Countries, Asia leads growing Energy Demand–in particular China & India
- Industry dominantes Energy Consumption–accounts for over 50%, Demand Increase 2018-2050 > 30%

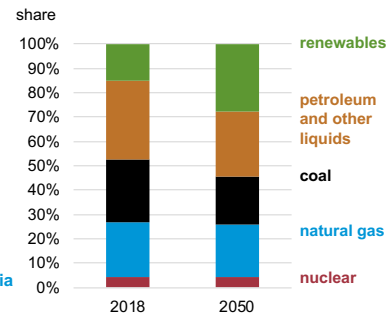
Global Energy Demand in Billion Btu



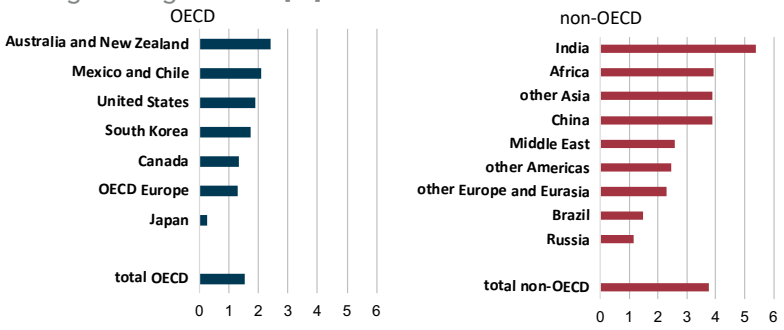
Energy Consumption non-OECD in Billion Btu



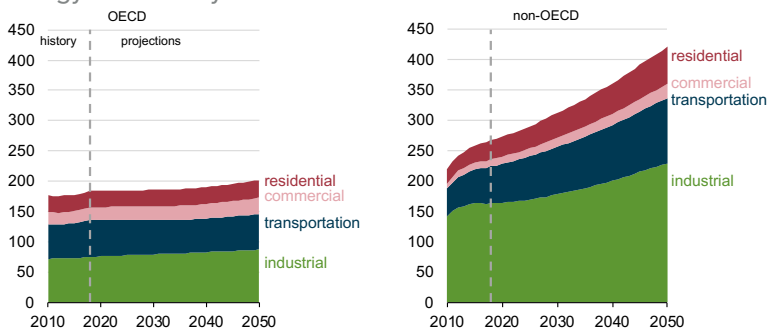
Primary Energy Consumption



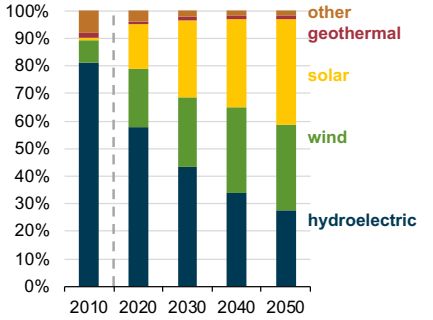
Average Change in GDP [%] 2018-2050



Energy Demand by Sector in Billion



Global RE Generation



Source: EIA, *International Energy Outlook 2019*, 24. September 2019

MARKETS – THE PV TERAWATT CHALLENGE

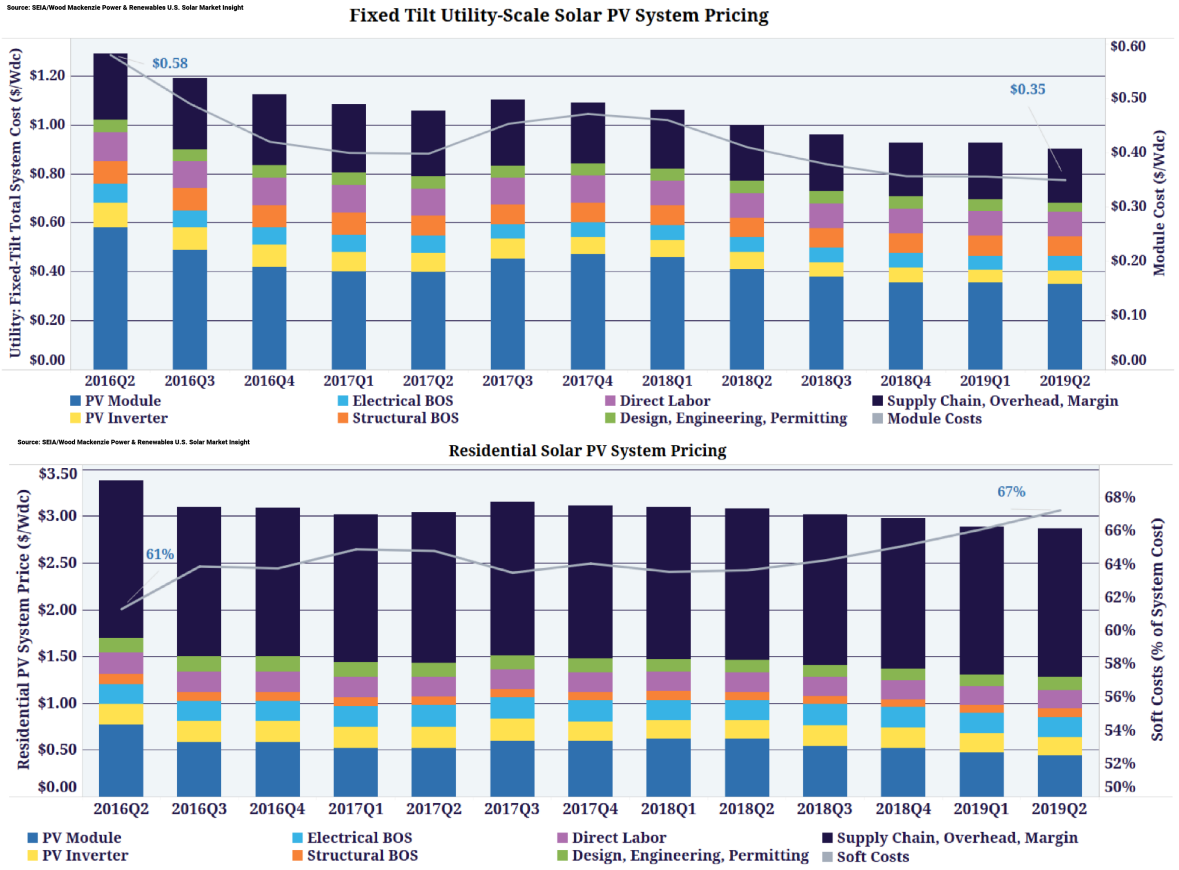
- Starting Scenario:
  - 2018 480GW installed PV Capacity
  - 2019 + 115GW installed PV Capacity–cumulative 594GW
  - 2020 + 127GW installed PV Capacity–cumulative 721GW
  - 2020 PV Modul mfg. Capacity ≈ 210–260GW (i.e. ≈ 100% Overcapacity), yet 2020–2023 Capacity Expansion Announcements at > 200GW
- Assumption:
  - By 2022/23 installed PV Capacity is expected exceed 1 TW
  - By 2030 3–10 TW
- Conclusion:
    - At least a 2-fold Increase of Module mfg. Capacity is required by 2030
    - It is reasonable to expect mfg. Capacity to grow by a Factor of 4–8x

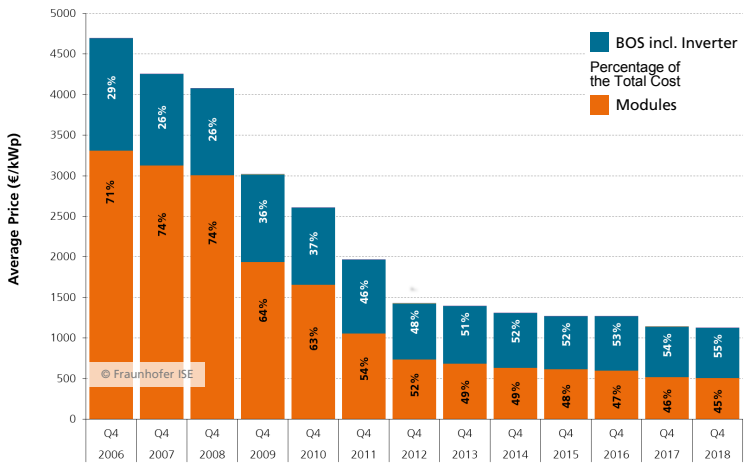
2030 Target (TW)	CAGR (%)	2030 Estimated Total Installed Annual Production Capacity (TW/y)
3	15	0.5
5	21	1.0
8	27	1.9
10	29	2.5

Source: Nancy M. Haegel et al., *Terawatt-scale photovoltaics: Trajectories and challenges*, Science 356 (2017)

MARKETS – MODULE COST

- Module Costs key Driver for PV Market Growth
  - ≈ ⅓ of System Costs (US, Utility-Scale)
  - 16–45% residential Rooftop





Source: SEIA, https://www.seia.org/solar-industry-research-data
Fraunhofer ISE, *Photovoltaics Report*, November 14, 2019

PV LANDSCAPE

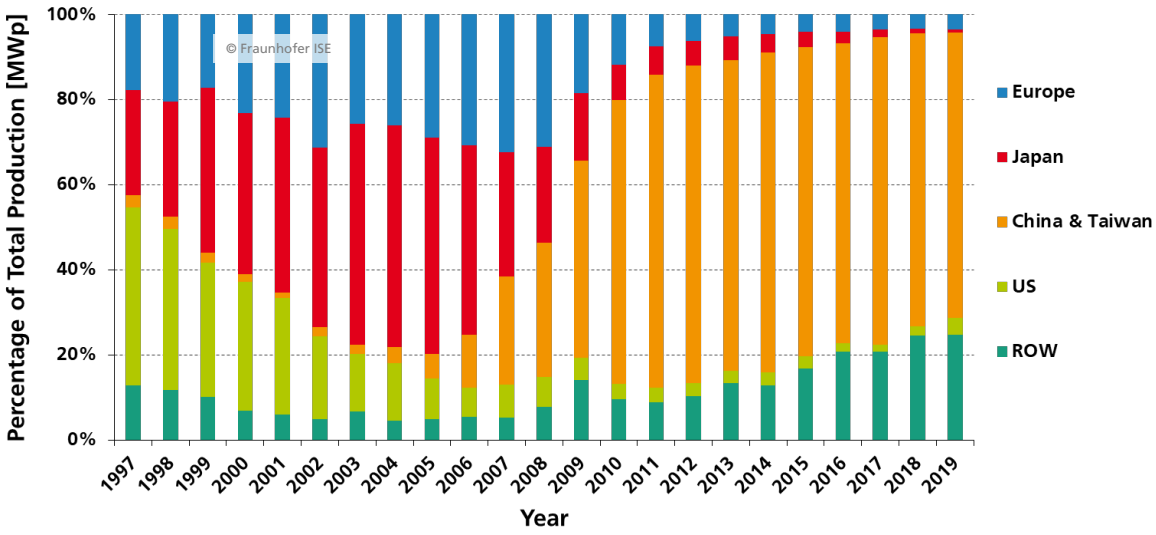
MANUFACTURING SUPPLY CHAIN

MANUFACTURING — SUPPLY CHAIN

- c-Si Module Cost in SE Asia ≈ ¢20–23/W
- US and Europe presently with insignificant PV Manufacturing Capacity
- China dominates the entire Supply Chain
  - 72% Poly
  - 95% Ingot
  - 99% Wafer
  - 80% Cells
  - 75–80% Modules

	Poly	Ingot	Wafer	Cell	Module	Inverter	Installation	Total
Cost* ($/W)	$0.03/W	$0.03/W		$0.04/W	$0.10/W	$0.06/W	$0.70/W	**$0.96/W**
Facility Capex	$35k/MT	$0.08/W		$0.05/W	$0.03/W	Additional components not listed here include low-iron glass, aluminum frame, polymer encapsulant, fluorinated backsheet, silver paste, copper ribbon, and junction box. *Excluding tax credits and tariffs		
Competitive Scale	10,000 MT	1000 MW		1000 MW	500 MW			
Competitive Investment	$350M	$80M		$50M	$15M			

Source: DOE/SETO, April 2021



Source: Fraunhofer ISE, *Photovoltaics Report*, September 16, 2020

MANUFACTURING – KEY MODULE MANUFACTURERS

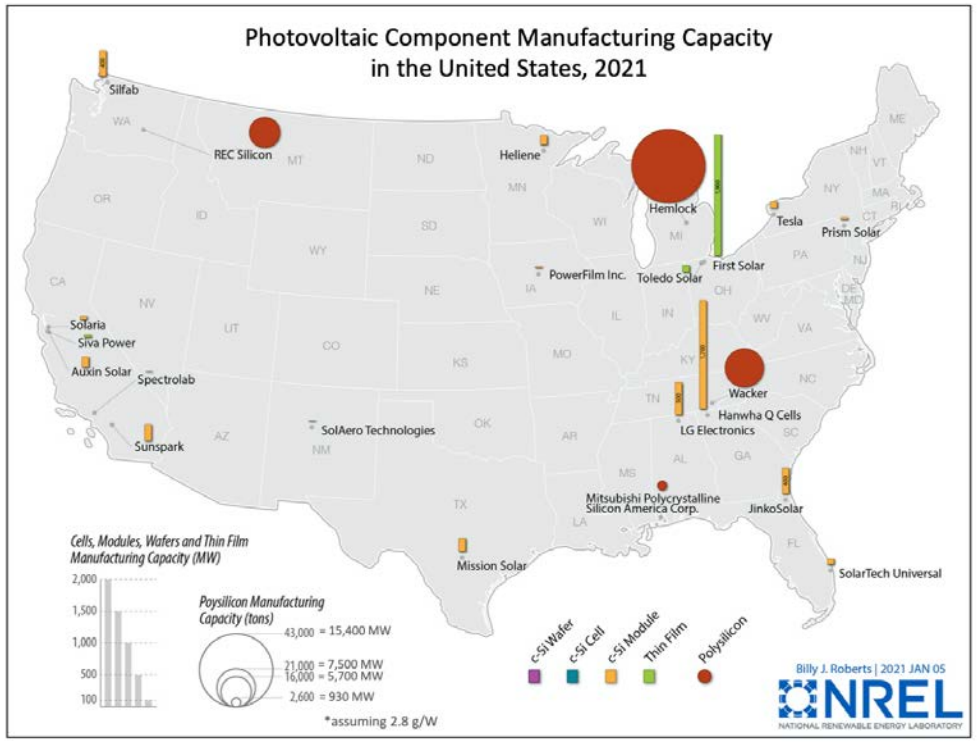
- 8 of the top 10 Module Suppliers are Chinese
- c-Si: the US has 6% of global Poly, 0% Ingot, 0% Wafer, 0% Cell Capacity; ≈ 15 Module Assembly Companies with ≈ 4GW Capacity
- The leading TF PV Supplier is FSLR with ⅓ of its Capacity in the US

Global solar photovoltaic module shipments ranking, 2019 — GlobalData.

2019 ranking	Solar PV manufacturer	Change vs 2018	2018 shipments	2019 shipments	% Growth
1	Jinko Solar Holding Co., Ltd.	-	11.4	14.2	25%
2	JA Solar Holdings Co Ltd	-	8.8	10.3	17%
3	Trina Solar Limited	-	8.1	9.7	20%
4	LONGi Solar Technology Co Ltd	-	7.2	9.0	25%
5	Canadian Solar Inc	-	7.1	8.5	20%
6	Hanwha Q CELLS Co., Ltd.	-	5.5	7.3	33%
7	Risen Energy Co., Ltd.	-	4.8	7.0	46%
8	First Solar Inc.	+3	2.7	5.5	104%
9	GCL System Integration Technology Co., Ltd.	-1	4.1	4.8	17%
10	Shunfeng Photovoltaic International Limited	-1	3.3	4.0	21%

Note: The preliminary results are based on the initial assessment of the shipments and are subject to change later

Source: GlobalData, Power Intelligence Center

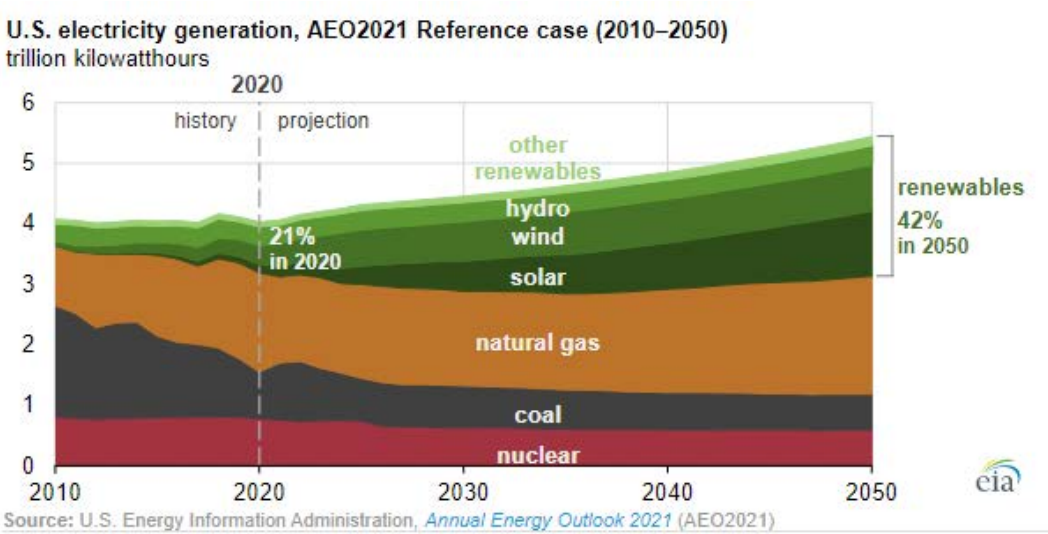


PROBLEM STATEMENT

WHAT & WHY

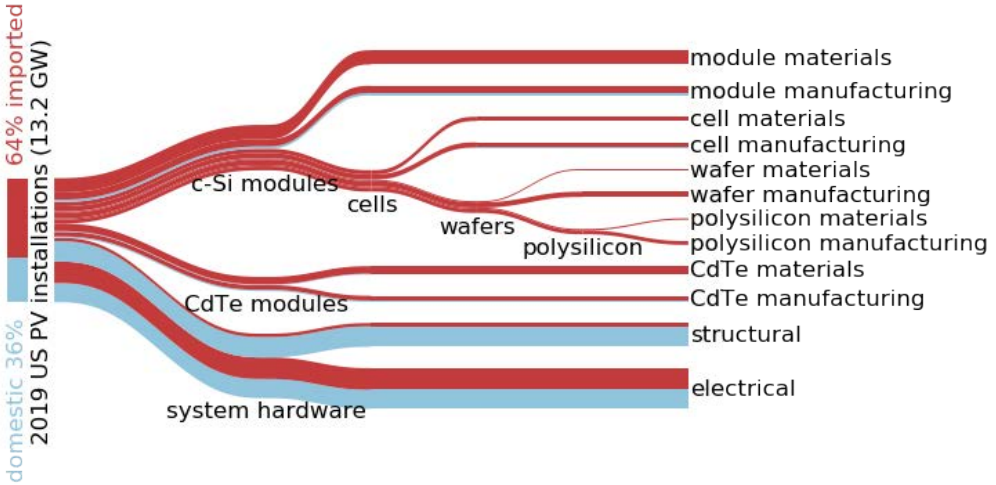
PROBLEM STATEMENT

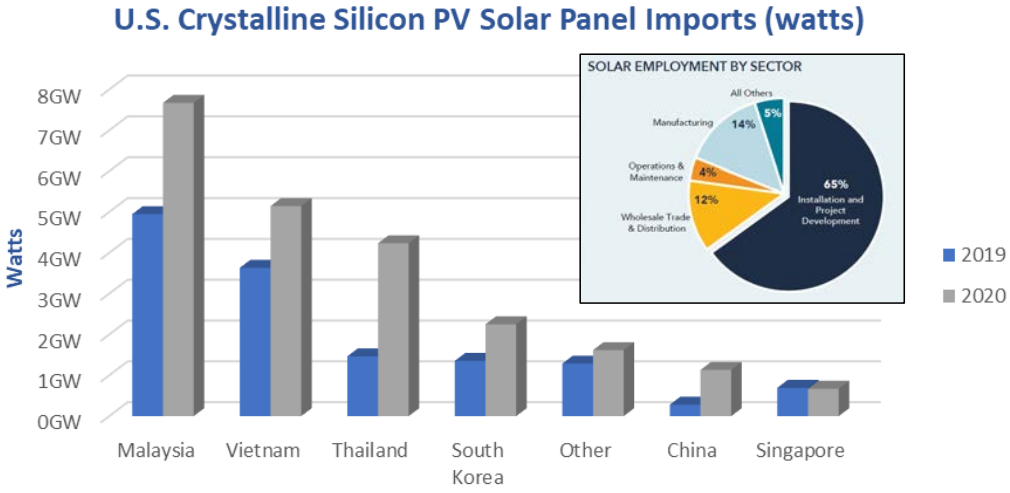
- The new Administration wants to:
  - Decarbonize the Economy by 2050–Carbon Pollution-free Electricity by 2035
  - Create „good-paying“ Jobs
  - Reduce the Trade Deficit with China/SE Asia
  - Strengthen Energy Independence and Grid Resilience



PROBLEM STATEMENT

- Yet,
  - we are importing > 98% of our Cells & Modules
  - are over-reliant on low-paying Jobs
  - have PV System Costs 3–3½x those of Australia, China, or Germany

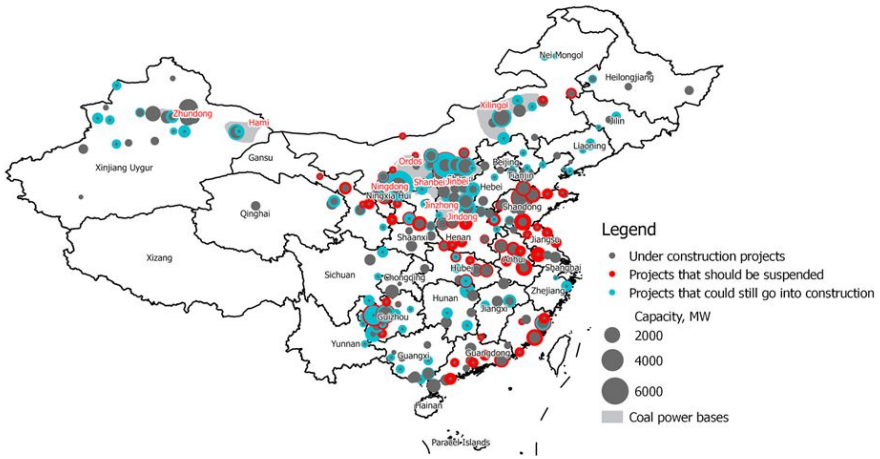




Source: DOE/SETO, NREL, April & May 2021

PROBLEM STATEMENT – ASPECTS OF SUSTAINABILITY

- Jobs & Labor Standards
  - In the US we employ about 230,000 Workers in the PV Industry, only 34,000 in PV Manufacturing
  - Adding 10GW of Manufacturing Capacity would create about 62,000 new, direct Manufacturing Jobs and about 75,000 indirect Manufacturing Jobs
  - Detention, Re-education, and Forced Labor of Muslims in the Xinjiang Region are well documented
  - US Law bans Imports of Goods produced with Forced Labor, yet PV Cells and Modules from Xinjiang are still imported
- Environmental Standards
  - ≈ 72% of Solar Grade Poly Silicon are made in China, ≈ 45% in Xinjiang Province; 100% based on Coal generating Capacity
  - Air, Water and Soil Pollution from PV Production in China are well documented
- The only „green" Investors know is the „mighty Dollar"



Source: World Resource Institute, Greenpeace, NDRC, company filings, 2016

THE DREAM

THE DREAM

(AS A SOLAR SCIENTIST) I HAVE A DREAM TOO. A DREAM OF A **CLEAN ENERGY FUTURE** WHERE **EVERY AMERICAN HAS THE CHANCE TO PARTICIPATE** IN THE CLEAN ENERGY ECONOMY, WHERE **WE RESPECT OUR PLANET AND OUR CITIZENS**, AND **VALUE** THE ROLE **ENERGY** PLAYS IN OUR LIVES.

POLICY

SUSTAINABLE DOMESTIC MFG.

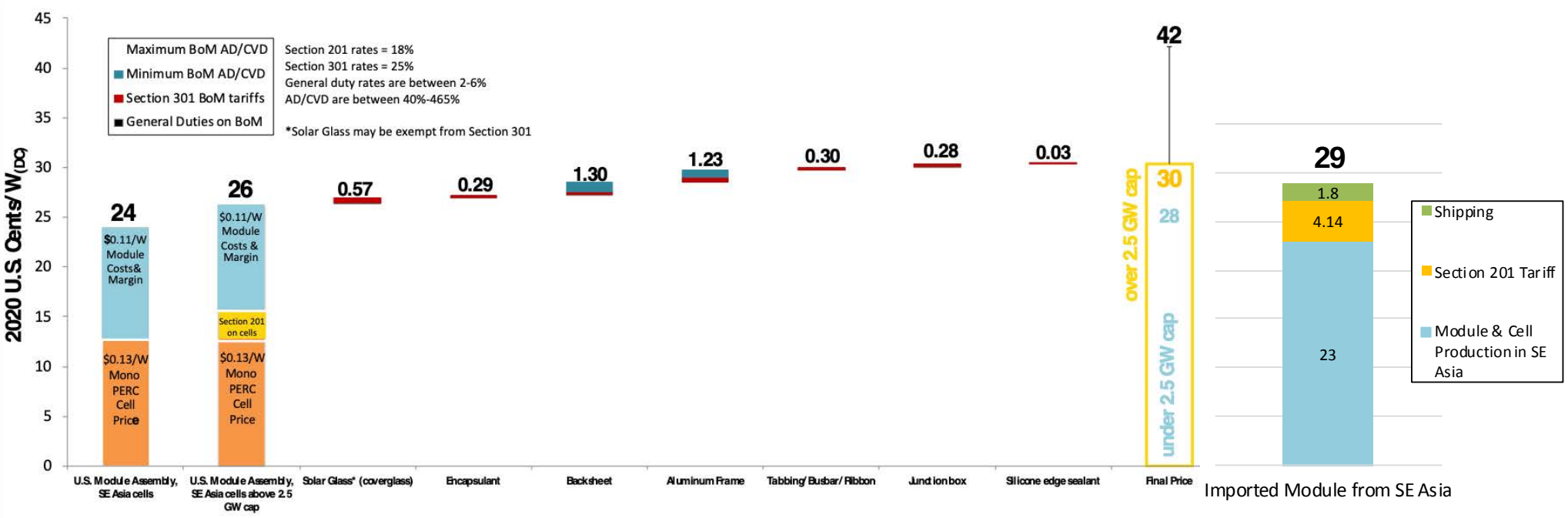
THE DREAM – CURRENT US POLICIES – TARIFFS

- Section 201:
  - Cells & Modules
  - 2018–2022 (?), Y1 30%, Y2 25%, Y3 20%, Y4 18%
  - 2.5GW of imported Cells excluded through Y3
  - TF & (initially) Bi-Facial PV excluded
- Section 301:
  - Cells, Modules & other Components
  - 2018–?, 25% in addition to 201 Tariffs

Source: DOE/SETO, April 2021

THE DREAM – DOMESTIC MODULE MANUFACTURING

- At ≈ 4GW Capacity Domestic Module Assembly from imported Cells is competitive
- We have ≈ 30GW of PV Grade Poly Silicon Capacity
- If we were to establish Ingot, Wafer & Cell Capacity at ≥ 5GW, we could be competitive
- Repatriating the remaining PV Module Supply Chain further enhances the Administration's Goals



Source: NREL, May 2021

THE DREAM – POLICY PROPOSALS

OPPORTUNITIES TO REESTABLISH DOMESTIC MANUFACTURING CAPACITY

A NEED FOR LONG-TERM VISION TO SECURE STRATEGIC INDUSTRIES—SUCH AS PV

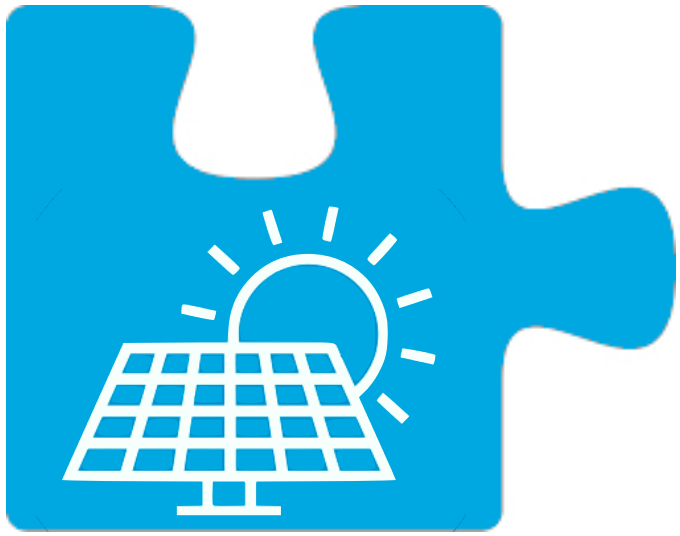
- A Combination of Policy Tools will be necessary to „spur" private Investment across the full PV Supply Chain AND sustain a US Solar Manufacturing Industry
  - Production Tax Credits-for all Segments of the Supply Chain
  - 48C Manufacturing Capacity Investment Tax Credit
  - Federal Procurement–not Domestic Content (incompatible to WTO), but e.g. CO_2 footprint
  - Increased Federal R&D Investment
  - ITC Extension

SUMMARY

CONCLUSIONS & OPPORTUNITIES

SUMMARY & CONCLUSIONS

- It isn't too late, we do't need a revolutionary, new Technology; but
  - The Window of Opportunity is closing fast
  - It is challenging to compete with China/SE Asia on established, commoditized c-Si Technology (p-type PERC), instead
  - We need to focus on, and accelerate deployment of advanced, low-cost, highest Efficiency c-Si Technologies (n-type IBC, HJT, TOPCon, BJ) and TF PV Technologies
- Long-term, consistent Policy is a Necessity to establish
  - A domestic Market big enough to entice Investment at all Levels of the Supply Chain, and to
  - Enable sustainable domestic Manufacturing



THANK YOU FOR YOUR INTEREST AND ATTENTION