dc + photovoltaics

Solution to Inexpensive Sustainable Electricity for Rich and Poor Alike

Frontier in Green Sustainable Energy: Paradigm Shift in Energy Efficiency of Existing Electricity Infrastructure by Phasing out AC Grid by End-to End Direct Current (DC) Power Networks

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INVITED TALK: UNSW Digital Grid Futures Institute, Australia

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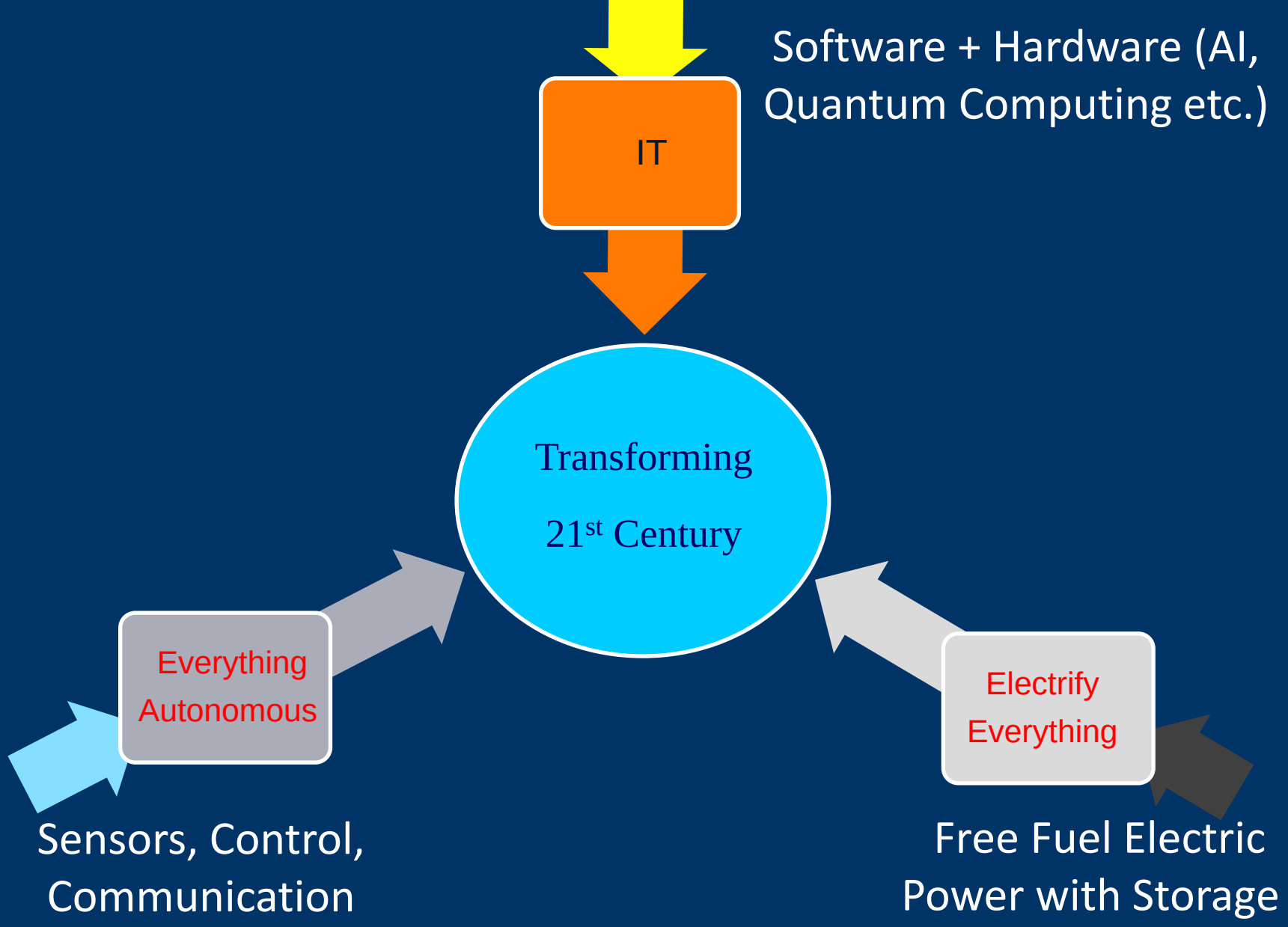
Introduction: Urgency to Get Away from Fossil Fuel , Source of Climate Emergency , Enemy of Sustainable Global Economic Growth, Enemy of World Peace , Public Policies

1973: I Decided to do PhD Thesis in the Area of Solar cells (Birth Year of Terrestrial Photovoltaics)

50th Anniversary of the 1973 Oil Embargo in 2023

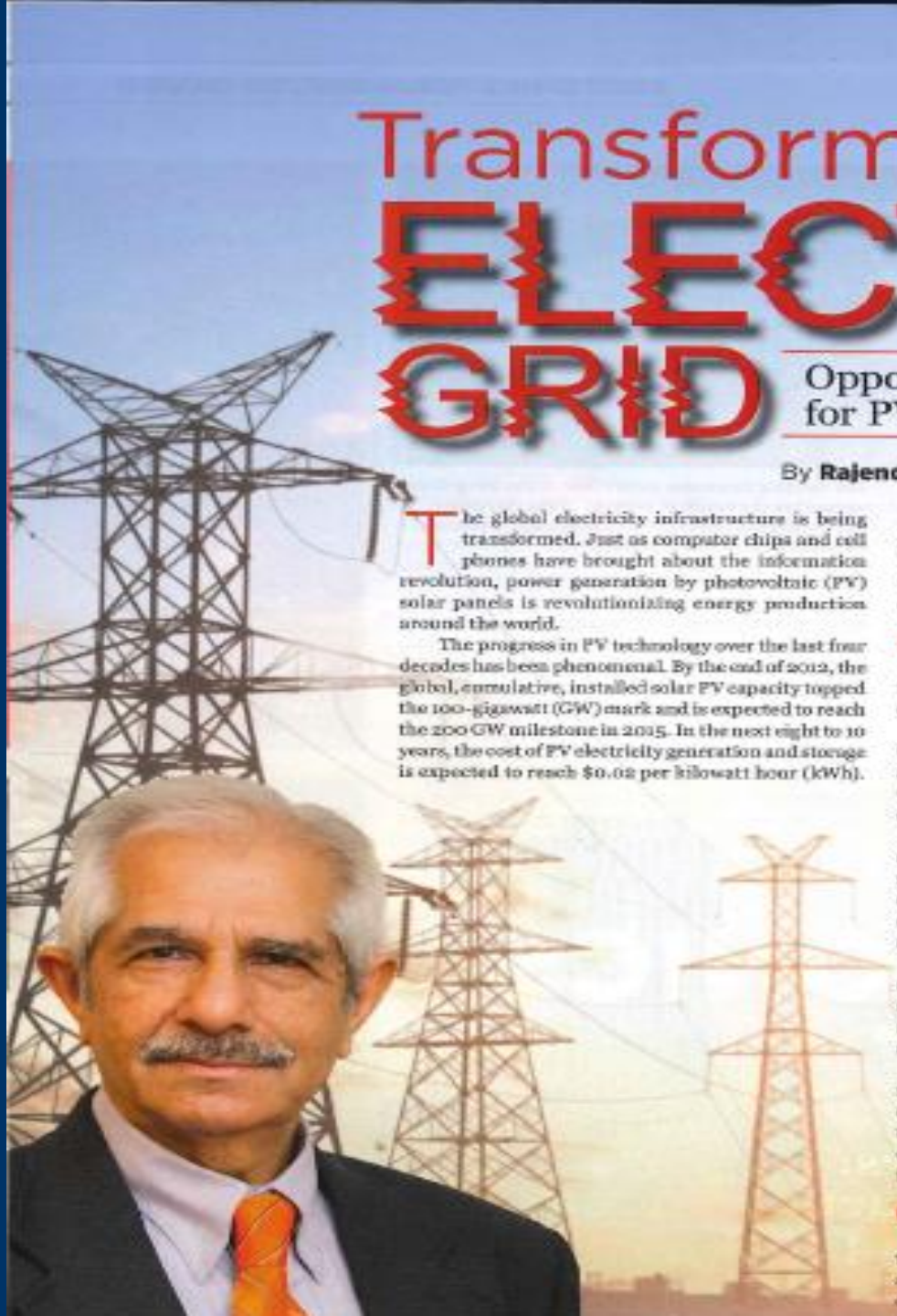
50 Years of Experience of Energy & Semiconductor Industries
(Energy & Information are two sides of the same coin)


Software + Hardware (AI, Quantum Computing etc.)
IT
Transforming
21st Century
Everything Autonomous
Sensors, Control, Communication
Electrify Everything
Free Fuel Electric Power with Storage

Transforming the ELECTRIC GRID

Opportunities and challenges for PV device design

By **Rajendra Singh**



The global electricity infrastructure is being transformed. Just as computer chips and cell phones have brought about the information revolution, power generation by photovoltaic (PV) solar panels is revolutionizing energy production around the world.

The progress in PV technology over the last four decades has been phenomenal. By the end of 2012, the global, cumulative, installed solar PV capacity topped the 100-gigawatt (GW) mark and is expected to reach the 200 GW milestone in 2015. In the next eight to 10 years, the cost of PV electricity generation and storage is expected to reach $0.02 per kilowatt hour (kWh).

Based on current trends in the reduced costs of installed PV systems and batteries, it is evident that local generation of direct current (DC) power by PV technology will emerge as a dominant source of low-cost energy in the 21st Century.

NEW TYPES OF ELECTRICITY GRIDS

One hour of incident solar energy, used as a free fuel and source of sustainable energy, is equal to all of the energy used in one year on Earth.

The aging electric-grid infrastructure around the world today is dominated by large, centralized alternating current (AC) power generation, high-voltage AC transmission, and medium-voltage AC distribution.

This infrastructure can be replaced by more energy-efficient and low-cost microgrids, a small-scale version of the main grid that could connect or disconnect with the larger grid, and nanogrids, which could generate, store, and distribute power without connectivity to the main grid.

The use of AC power to service DC loads results in a significant amount of energy loss. However, most of the electric load is spent on cell phones, laptops, air conditioners, light sources, home appliances, and other devices that operate on DC power.

Solar panels produce DC power. Electricity-storage devices (e.g., batteries and capacitors) store electricity in its DC form. Replacing AC electricity with DC electricity will save a substantial amount of energy normally lost in unnecessary conversions from DC to AC and vice versa.

CHEAPER, CLEANER FUEL

Reducing energy costs is particularly critical for the manufacturing industry, which, in some cases, spends as much as one-third of its operating cost on electricity. Microgrids and nanogrids that would

Clemson University professor leads global effort to transform power grids (1-4-24)

- 28 Committee Members from US, Europe, China, India, Brazil and New Zealand (Mostly industry Leaders , only six from academia)
- https://news.clemson.edu/clemson-university-professor-leads-global-effort-to-transform-power-grids/

Examine Power Systems of Today and Future

- Geo Politics, and Climate Emergency
- We focus on Technical and Economic Challenges
- System Approach: Power Generation, Transmission , Distribution, and Utilization must be coupled together to find the sustainable solution that will be propelled by Market forces
- R. Singh and V. Powar, “The Future of Generation, Transmission, and Distribution of Electricity”, Invited Book Chapter by Eds. A. Lakhtakia, C. M. Furse, & T. G. Mackay, *The world of applied electromagnetics: In appreciation of Magdy Fahmy Iskander. Springer International Publishing*, 2024 (In Press)

ELECTRIC POWER GENERATION

Some Key Facts in Energy Conversion

- Laws of Thermodynamics are applicable for all length scales.
- Laws of Physics can not be changed with any amount of resources (time & money)
- The Environmental issues can not be ignored .
- During the life time of a particular conversion device the energy converted must be much more than the energy consumed in the manufacturing of a particular device. This will dictate the economics of a particular process or method.
- Only free fuel conversion devices are sustainable
- In any energy conversion device waste energy is generally heat
- Conservation of water is an absolute necessity for mankind
- For supply-chain control, abundance of the raw materials used in energy conversion is an absolute necessity. (R. Singh & J. D. Leslie, Solar Energy, 1980). Based on this concept we stressed silicon as an ideal photovoltaic material.

Sustainable & Inclusive Power Matrix

- Free Fuel Based Energy (only Solar, Wind and Ocean waves Qualify)
- Electric power Based Transportation
- Ultra-low Cost
- Resiliency Against Man made (cyber security, Electro Magnetic Protection) and Natural Threats (Solar Storm, Hurricanes etc.)
- Minimal Impact on the Eco-system (water, air and earth)
- Access to All (Eradication of Energy Poverty will lead to Poverty Reduction)
- Minimal Adverse Impact on Health
- Reduction of Health Bills and improve quality of life for Aged Population
- Highest Energy Efficiency at all levels (Direct Current Power & Internet of Things as Enablers)
- Highest Re-use and recycle of All products
- Save Trees and plant more trees

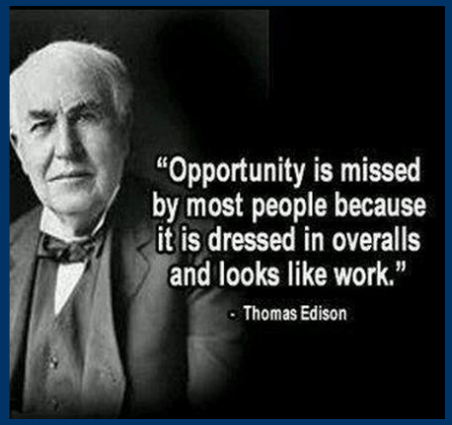
Difference Between Green and Clean Electric Power

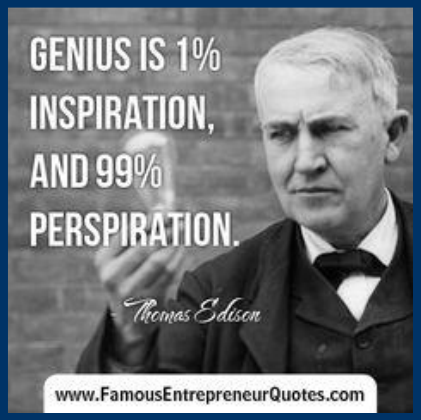
- There are fundamental differences between green and clean energy sources. Free fuel and renewable green energy sources such as solar and wind have negligible negative impact on the environment and require minimum use of water in electric power generation. On the other hand, clean energy source such as nuclear energy does not produce GHG emission during electric power generation, but mining, extraction, and long-term radioactive waste storage are threats to the environment, and Uranium is a nonrenewable resource. In addition, nuclear energy requires massive amount of water in electric power generation. Thus, renewable, and free fuel-based solar and wind power that have minimal negative impact on the environment are considered as green sustainable power.
- R. Singh, P. Paniyil and Z. Zhang, "Transformative Role of Power Electronics: In solving climate emergency," in *IEEE Power Electronics Magazine*, vol. 9, no. 2, pp. 39-47, June 2022, doi: 10.1109/MPEL.2022.3169317

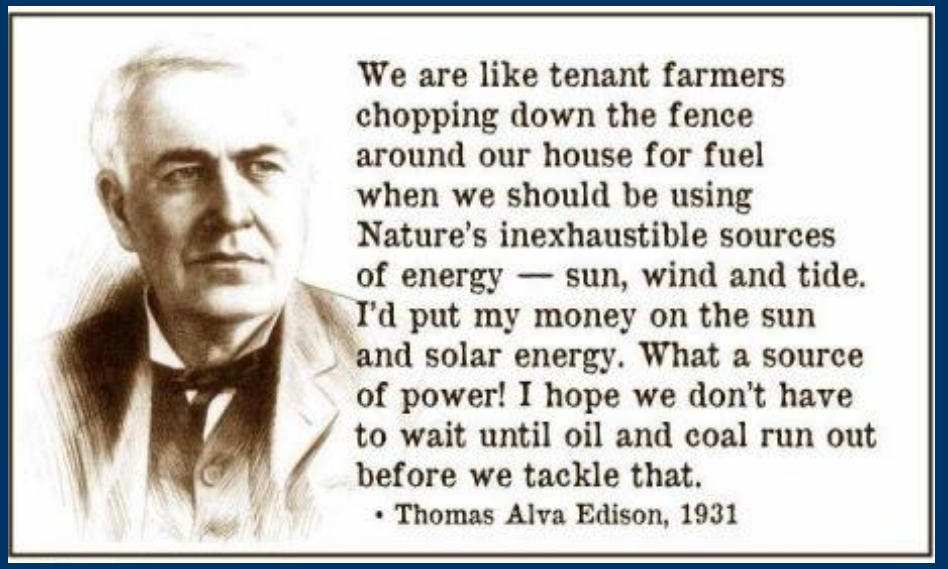
First Mantra of Rigveda

- Om agnimide purohitam. Yagyasya devamritwijam. Hotaaram ratnadhaatmam
- I glorify the Self-effulgent God the Supreme Leader, the Eternal Support of the Universe, the Illuminator of all noble activity, the only object of adoration in all seasons and the most Bounteous and the Greatest Bestower of splendid wealth.
- Agni is a cosmic force with the qualities of light (or knowledge) and power in perfect harmony.
- Sun as the Source of all forms of Energy

Edison's Vision

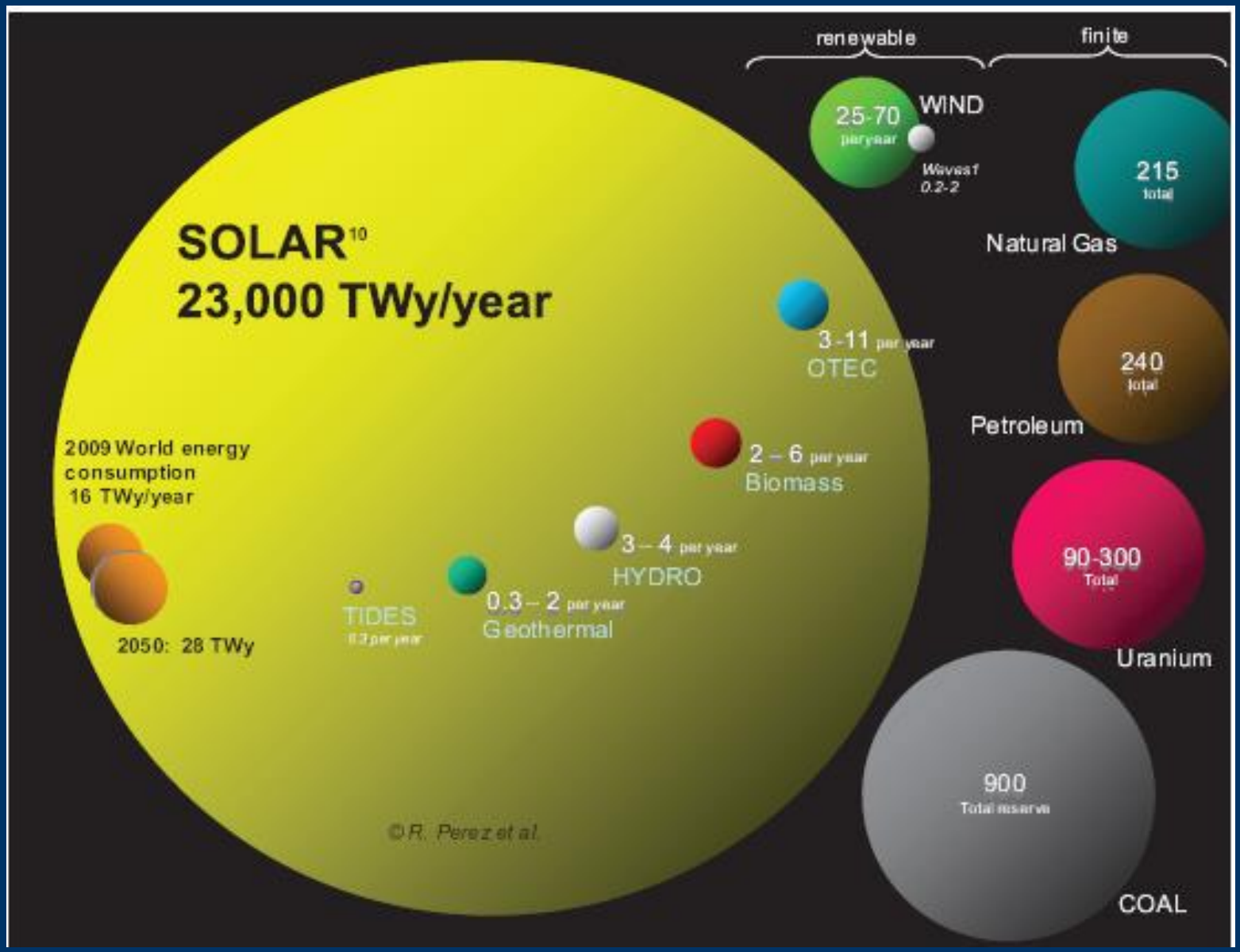






Edison wanted to "electrify" New York City. His vision was to put metal wires on poles above the city streets, to carry current to every house. Because energy is lost in those wires (from their resistance) the energy could not be transported very far. He saw that creating such a system was no real problem: he would place an electric power generator in every neighborhood, so the wires would never be more than a few blocks long.

Free Solar Energy: More Than the Needs of Mankind

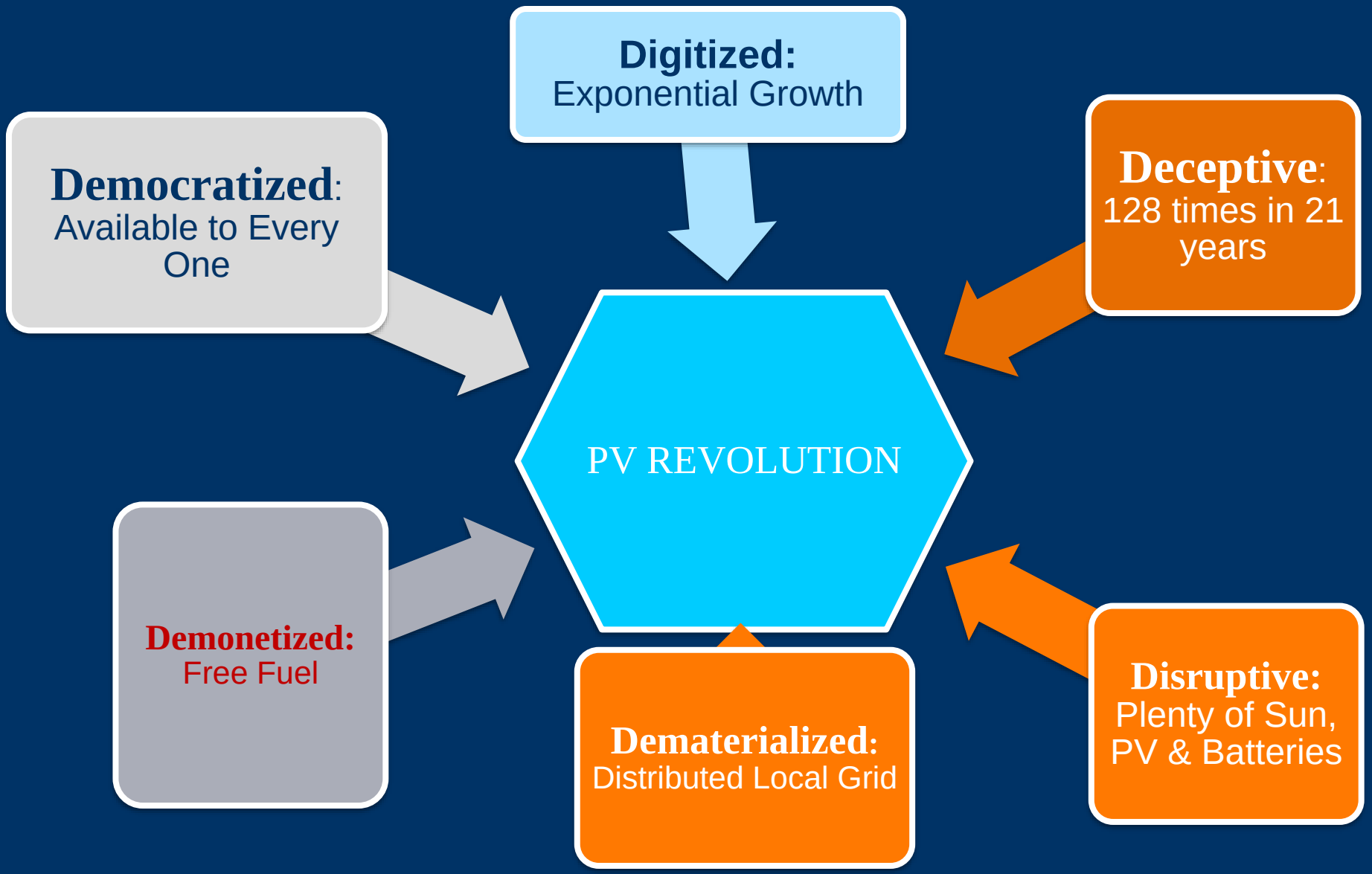


Brief Commercial History of Terrestrial Photovoltaics

- At the time of energy crisis of 1973, Silicon cell efficiency was ~13%
- J. Shewchun, R. Singh, and M.A. Green, "Theory of Metal-Insulator-Semiconductor (MIS) Solar Cells", **J. Appl. Phys.**, 1977, Vol. 48, pp. 765-770.
- R. Singh, M.A. Green, and K. Rajkanan, "Review of Conductor-Insulator-Semiconductor (CIS) Solar Cells", **Solar Cells**, 1981, Vol. 3, pp. 95-148.
- No commercial market till 1999
- In 1999 Dr. Green announced 25 % Efficient Silicon Solar Cells
- Artificial market created by subsidies , First by Japan, Then German followed by the rest of the world
- PV market started to Grow.
- Chinese companies “Suntech” formed by Ex student of Dr. Green, Leader in the commercial field
- Financial Crisis of 2007-2008, Market Collapsed
- 2010 China Invested heavily, rest is history
- Both Dr. Green and my pioneering work on conductor –tunneling- insulator - semiconductor solar cells is now beginning to dominate photovoltaic manufacturing in the form of TOPCon (tunnel oxide passivated contact) cells

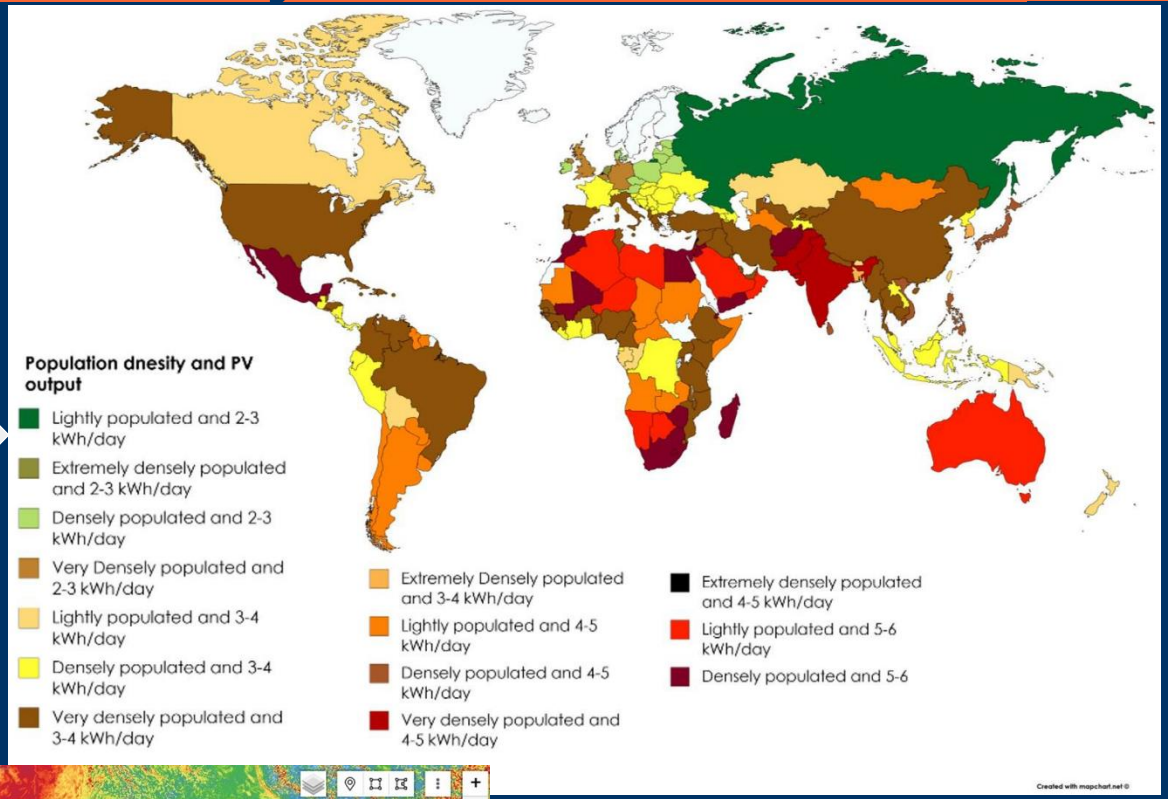
Six D's Drivers of PV Revolution

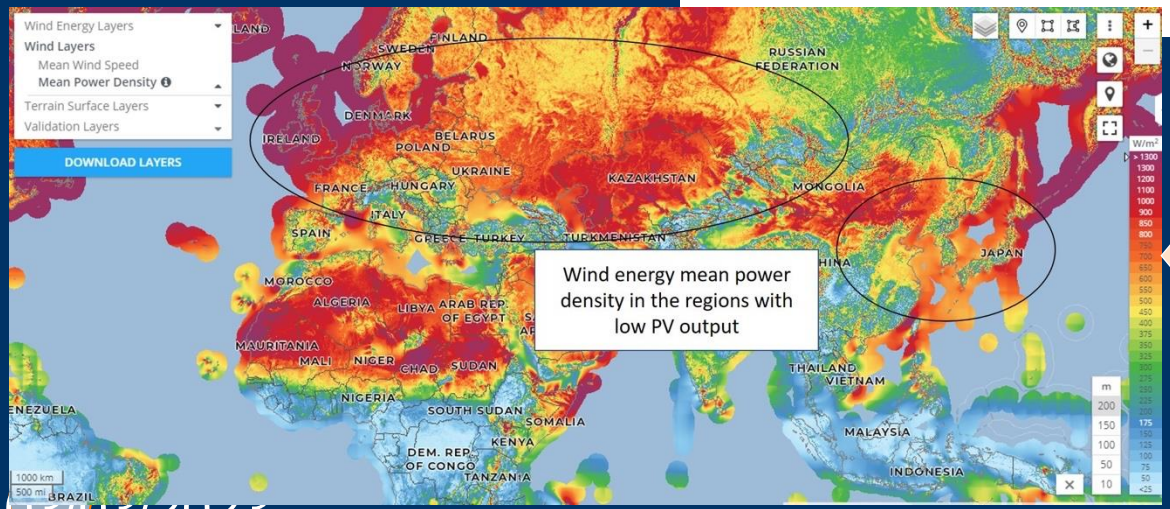
http://www.forbes.com/sites/peterdiamandis/2014/09/02/solar-energy-revolution-a-massive-opportunity



100 % Power to the World by PV and Wind (IEEE PVSC 2021)

Global PV output overlayed with population density for all nations across the globe





Availability of Wind energy power density in regions with lower PV output

My Prediction on Wind & Solar Energy in 2010

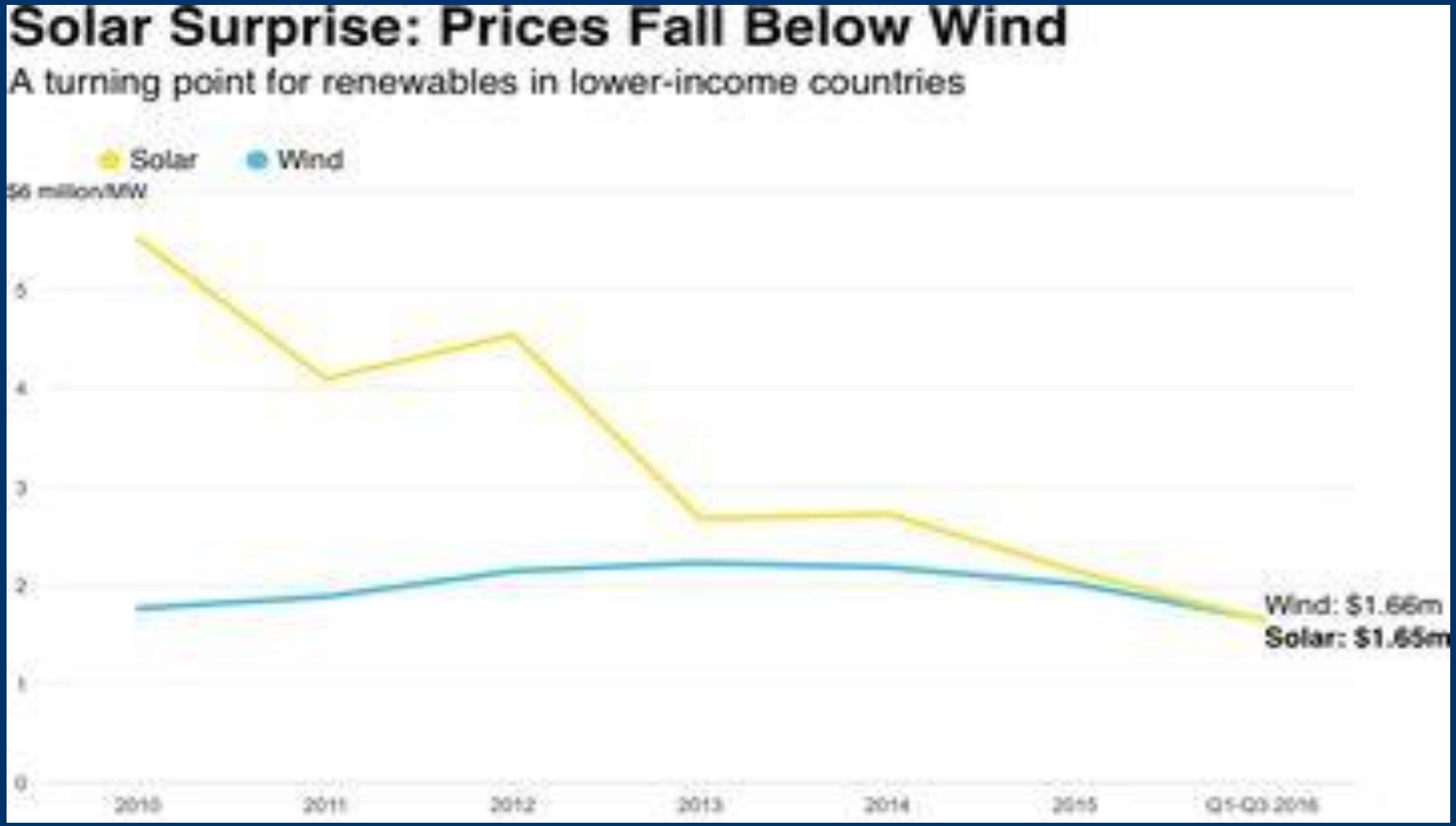
- In 2010, Dr. Green and I were selected globally as one of the ten global champions of Photovoltaics (PV) Technology.
- As part of the award acceptance I stated that we have examined every energy source and other than free fuel based photovoltaics (PV) and wind there is no other sustainable energy solution
- I also stated that due to inherent advantages, PV will take over wind and eventually we will have PV as the dominant electricity generation technology
- **http://www.renewableenergyworld.com/articles/2010/10/champions-of-photovoltaics.html**

Why and How Photovoltaics Will Provide Cheapest Source of Electricity in the 21st Century

- R. Singh, G. F. Alapatt and G. Bedi
- FACTA UNIVERSITATIS
- Series: Electronics and Energetics, Vol., No 2, June 2014, pp. 275-298
- DOI: 10.2298/FUEE1402275S
- If the current trends of PV growth continue, we expect PV electricity cost with storage to reach $0.02 per kWh in the next 8-10 years.

World Energy Hits a Turning Point: Solar That's Cheaper Than Wind

https://www.bloomberg.com/news/articles/2016-12-15/world-energy-hits-a-turning-point-solar-that-s-cheaper-than-wind

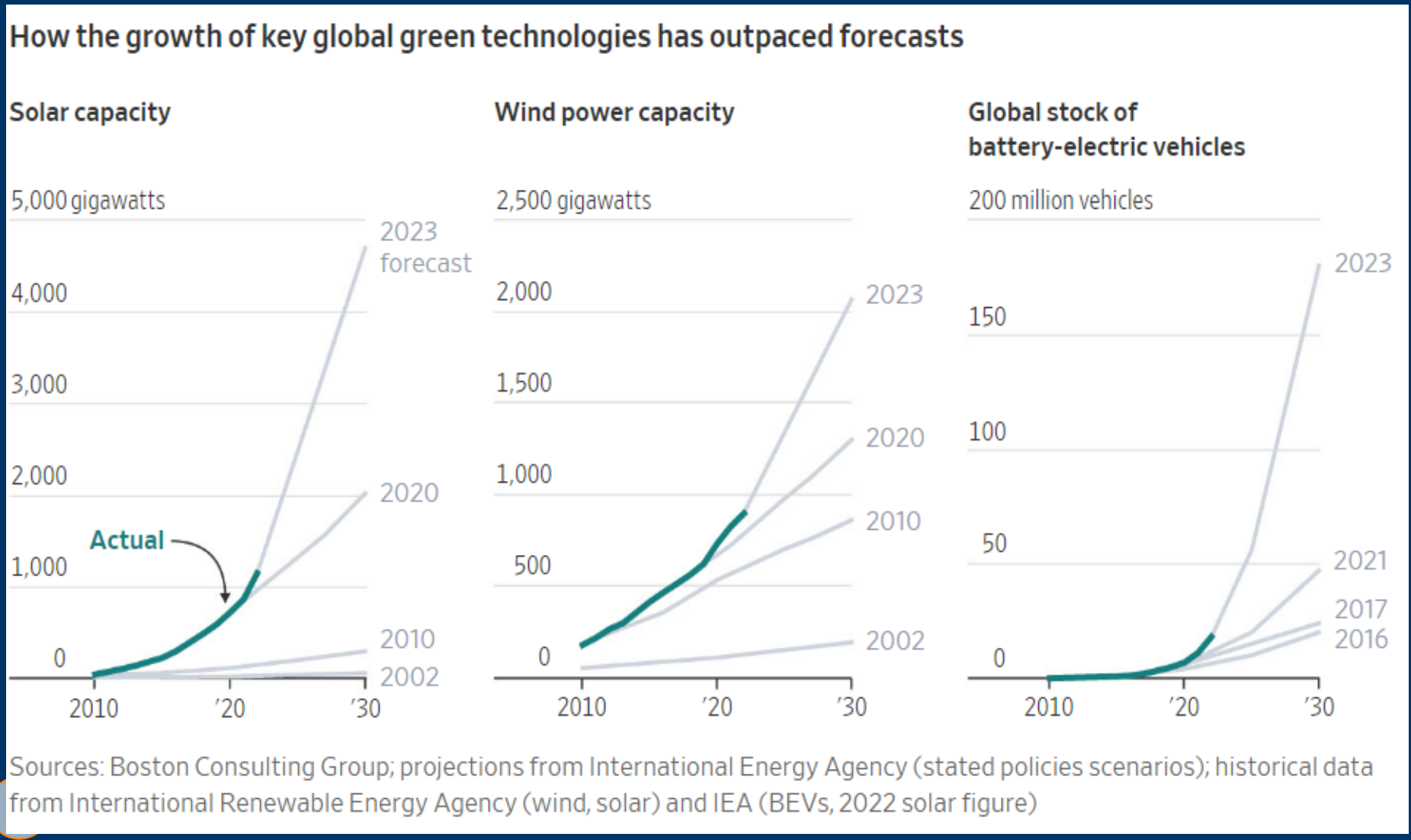


End of 2023 Global Installed Solar & Wind Energy

- PV: 413GW + 1185 GW= 1598 GW
- https://pv-magazine-usa.com/2023/11/28/solar-surging-58-in-2023-413-gw-of-installations-expected-globally/
- 906 + 77 GW = 983 GW Wind
- https://www.windpowermonthly.com/article/1856694/windpower-intelligence-global-forecast-january-2024#:~:text=North%20America,24GW%20of%20this%20being%20offshore

Now for Some Good News About Climate
Costs for renewables have plummeted and growth is exceeding expectations

https://www.wsj.com/business/energy-oil/now-for-some-good-news-about-climate-27236f56?mod=djemSustainableBusinessPro



batteries

MDPI

Article

Further Cost Reduction of Battery Manufacturing

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Academic Editor: Maciej Swierczynski
Received: 14 February 2017; Accepted: 12 May 2017; Published: 1 June 2017

Abstract: The demand for batteries for energy storage is growing with the rapid increase in photovoltaics (PV) and wind energy installation as well as electric vehicle (EV), hybrid electric vehicle (HEV) and plug-in hybrid electric vehicle (PHEV). Electrochemical batteries have emerged as the preferred choice for most of the consumer product applications. Cost reduction of batteries will accelerate the growth in all of these sectors. Lithium-ion (Li-ion) and solid-state batteries are showing promise through their downward price and upward performance trends. We may achieve further performance improvement and cost reduction for Li-ion and solid-state batteries through reduction of the variation in physical and electrical properties. These properties can be improved and made uniform by considering the electrical model of batteries and adopting novel manufacturing approaches. Using quantum-photo effect, the incorporation of ultra-violet (UV) assisted photo-thermal processing can reduce metal surface roughness. Using in-situ measurements, advanced process control (APC) can help ensure uniformity among the constituent electrochemical cells. Industrial internet of things (IIoT) can streamline the production flow. In this article, we have examined the issue of electrochemical battery manufacturing of Li-ion and solid-state type from cell-level to battery-level process variability, and proposed potential areas where improvements in the manufacturing process can be made. By incorporating these practices in the manufacturing process we expect reduced cost of energy management system, improved reliability and yield gain with the net saving of manufacturing cost being at least 20%.

Keywords: lithium-ion (Li-ion) battery; battery manufacturing; advanced process control (APC); rapid thermal processing; industrial internet of things (IIOT)

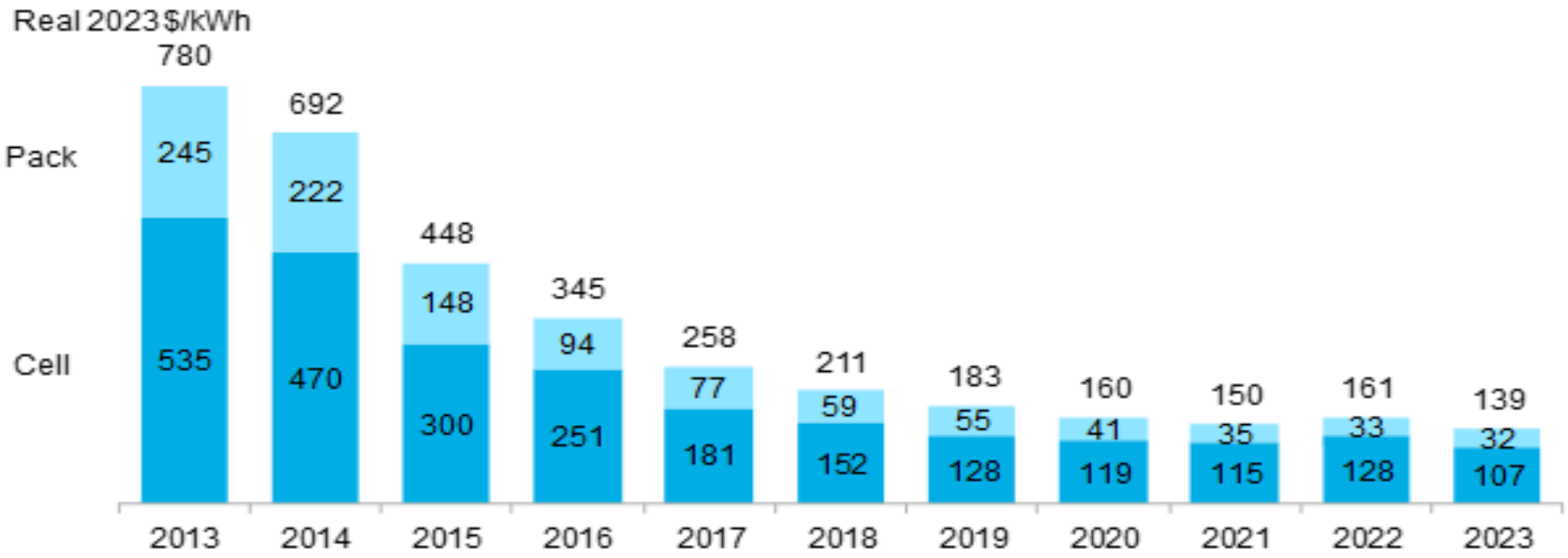
1. Introduction

Energy storage has evolved at a rapid rate in the last couple of decades. For a long time, battery storage was mostly used for starting engines, few emergency backup and portable devices, toys, etc. Ubiquitous zinc-carbon (dry cell) battery and lead-acid battery were the key players for

Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh (11-26-2023)

https://about.bnef.com/blog/lithium-ion-battery-pack-prices-hit-record-low-of-139-kwh/

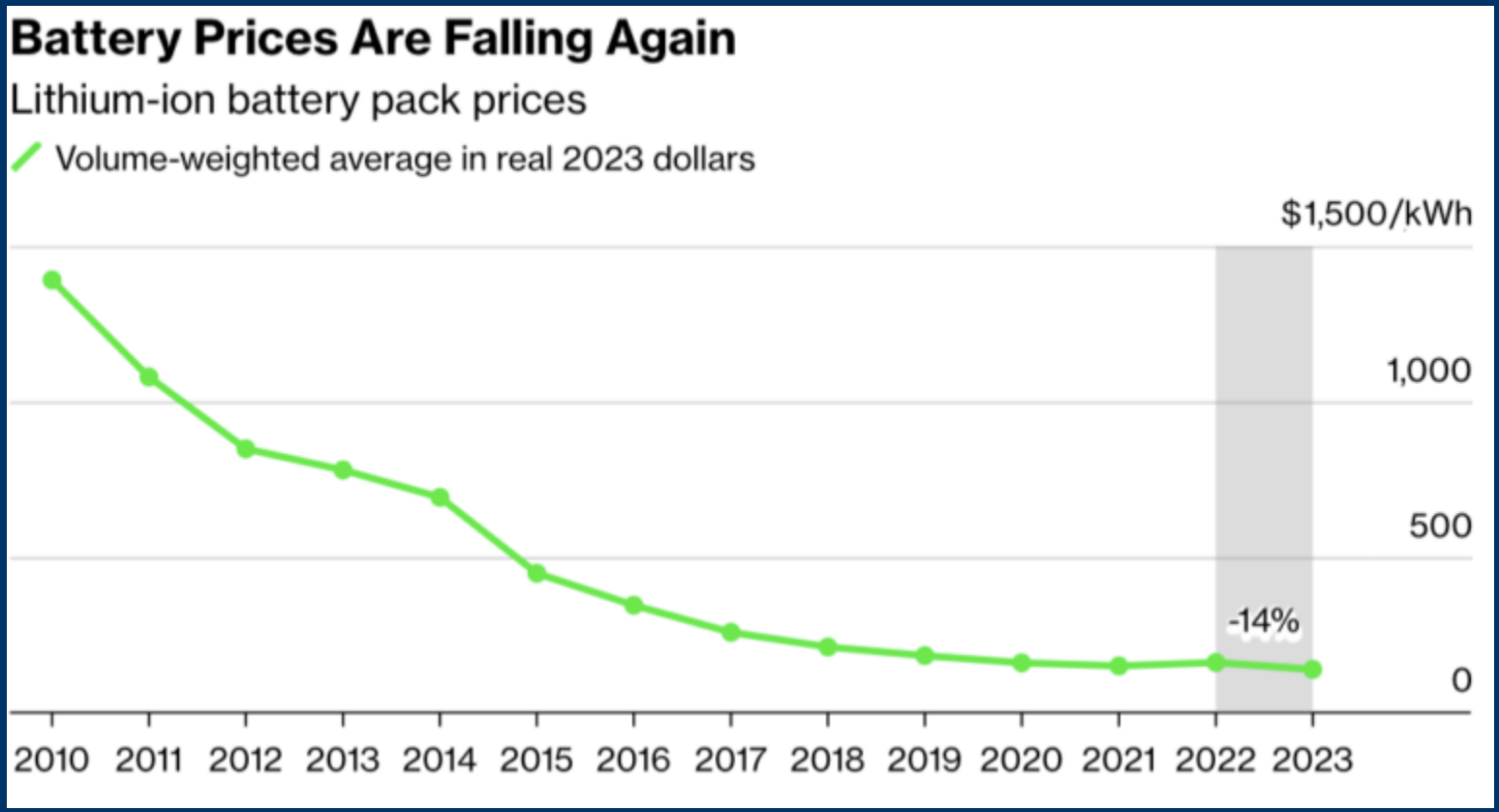
Figure 1: Volume-weighted average lithium-ion battery pack and cell price split, 2013-2023



Source: BloombergNEF. Historical prices have been updated to reflect real 2023 dollars. Weighted average survey value includes 303 data points from passenger cars, buses, commercial vehicles, and stationary storage.

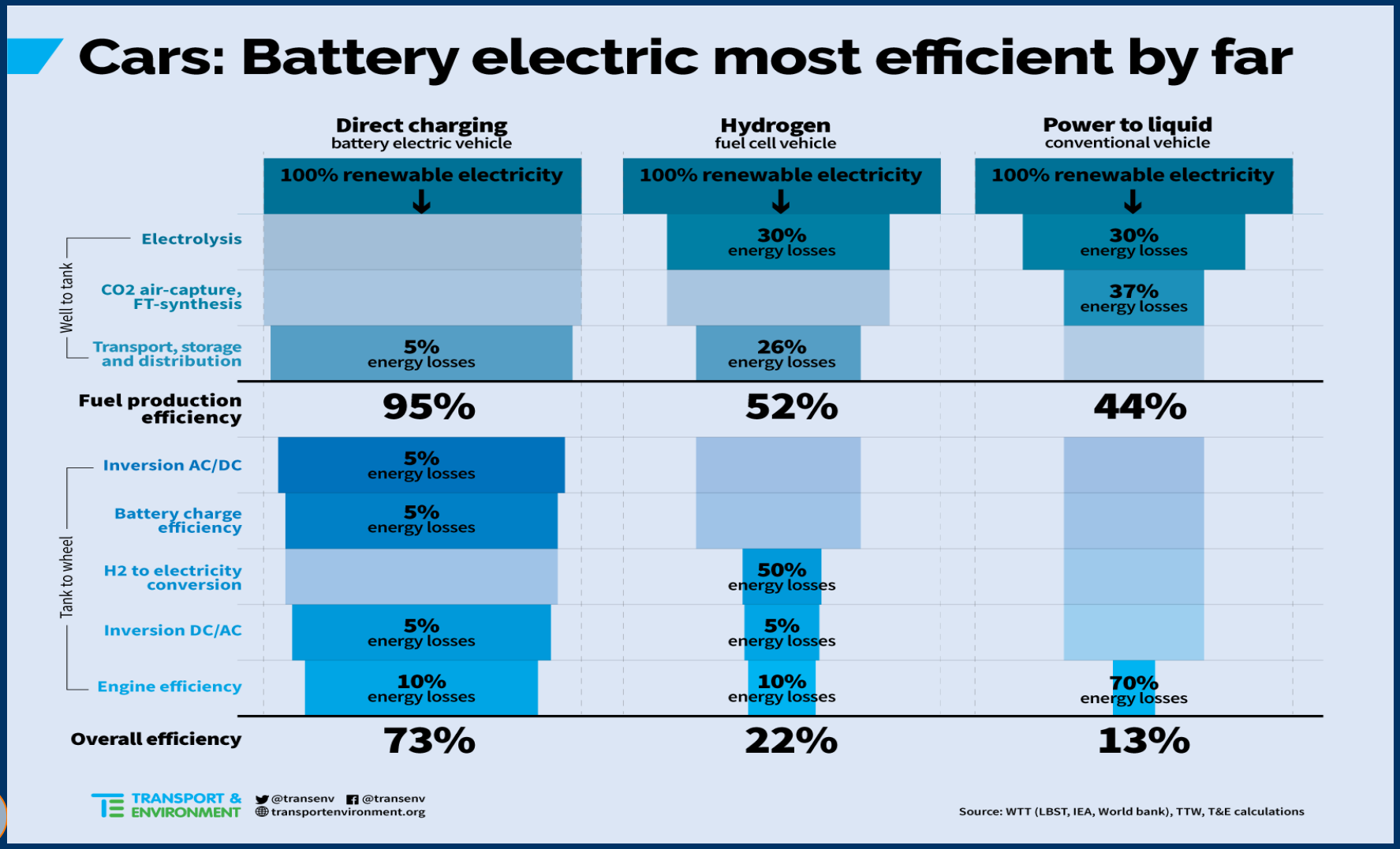
Battery Prices Down 14% This Year, says BloombergNEF”, (12-1-23)

https://www.pv-magazine.com/2023/12/01/battery-prices-down-14-this-year-says-bloombergnef/



EVs: Hydrogen Fuel Cells Add Excessive Complex Technology & Cost

https://insideevs.com/news/443711/hydrogen-fuel-cell-cars-complex-costly-impractical/



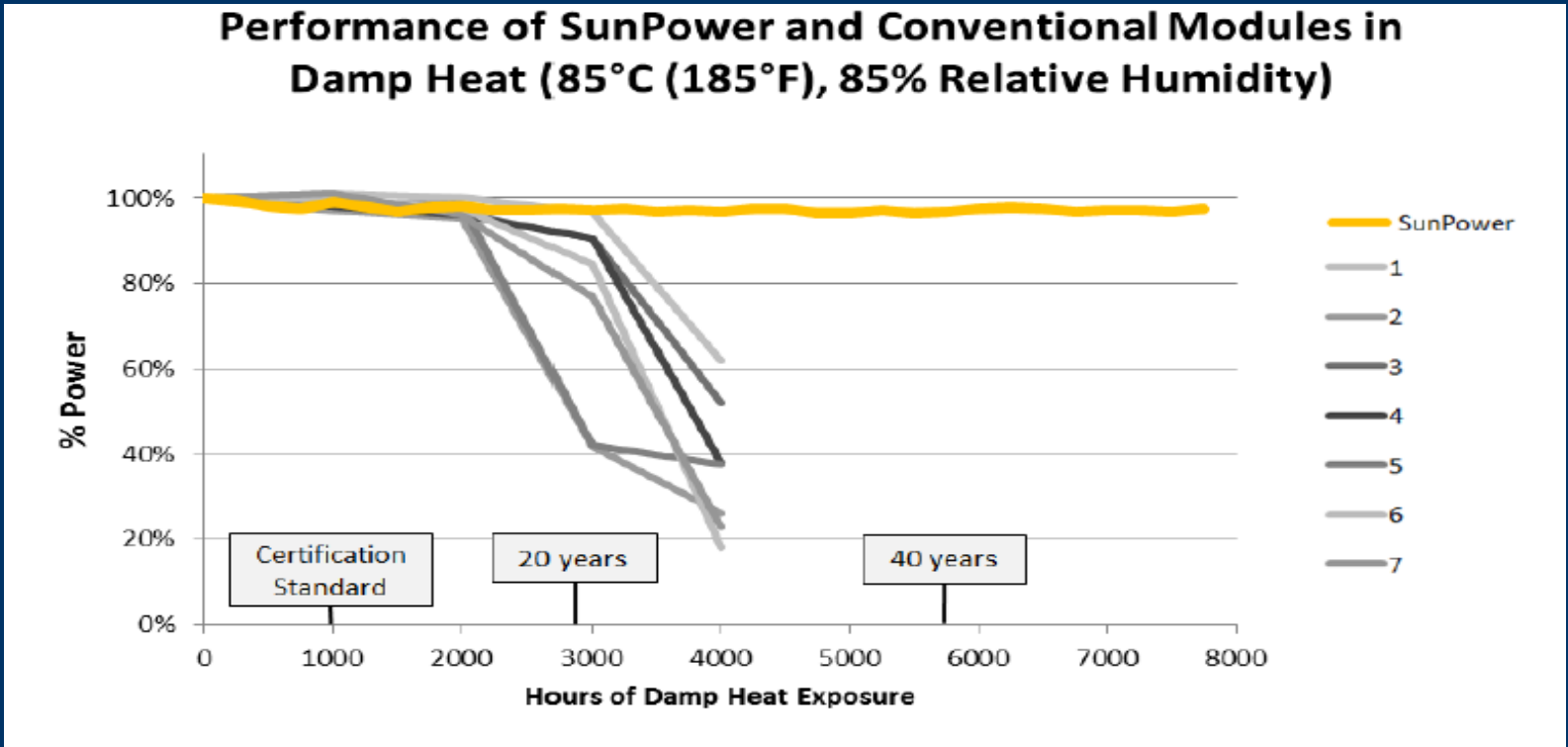
Tesla Powerwall Survive Hours Under water In Hurricane Ian (October 2, 2022)

- This Tesla Solar Roof and Powerwall stood up to the challenge of Hurricane Ian in Florida last week. https://cleantechnica.com/2022/10/02/tesla-solar-roof-powerwall-survive-hours-underwater-in-hurricane-ian/

Manufacturer : 25-30 years Warranty

http://us.sunpower.com/sites/sunpower/files/media-library/data-sheets/ds-x21-series-335-345-residential-solar-panels-datasheet.pdf

- Sun Power: 40 Years Useful Life (99 % of Modules will provide 70 % Power)
- http://us.sunpower.com/sites/sunpower/files/media-library/white-papers/wp-sunpower-module-40-year-useful-life.pdf



SEG Solar unveils 700 W TOPCon solar modules with 22.53% efficiency (2-15-24)

- SEG Solar says its new panels have a temperature coefficient of -0.30% per C. They come with a 30-year power output guarantee for 87.4% of the initial yield.
- https://www.pv-magazine.com/2024/02/15/seg-solar-unveils-700-w-topcon-solar-modules-with-22-53-efficiency/

This 100% solar community endured Hurricane Ian with no loss of power and minimal damage (October 2, 2022)

https://amp.cnn.com/cnn/2022/10/02/us/solar-babcock-ranch-florida-hurricane-ian-climate/index.html

Battery Storage Cost Calculations

https://www.mdpi.com/1996-1073/14/10/2772

Methodology

- Geographic consideration
- PV Irradiation Profile
- System Sizing

Operation and Results

- Decision Tree Approach
- Assumptions and Losses
- Charge-discharge battery profile for cloudy days

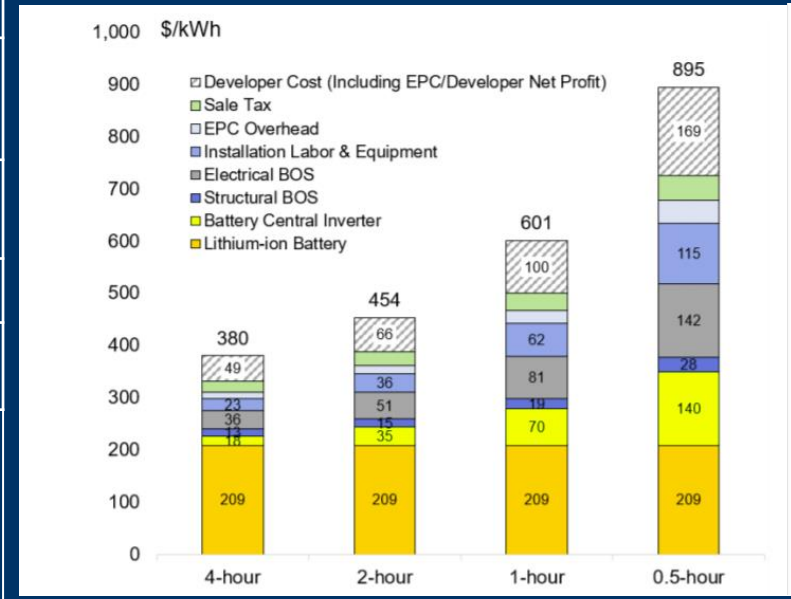
Economic Feasibility and System Costs

- 16 hour BESS costs
- Variable debt rate

- Utility scale battery storage costs only available for 4 hours of operation; we need 16-18 hours of storage operation
- Levelized Cost of Storage (LCOS) makes several assumptions.
- DOE-NREL's utility scale 60 MW storage, cost varies with duration of operation as:

Storage Costs ($/kWh) = Battery Pack Cost ($/kWh) + (EOS+ BOS + Labor +Other cost)/ (Storage System Size*Duration of Hours)

2018 costs; battery pack price at $209/ kWh



2021 costs; battery pack price at $137/kWh

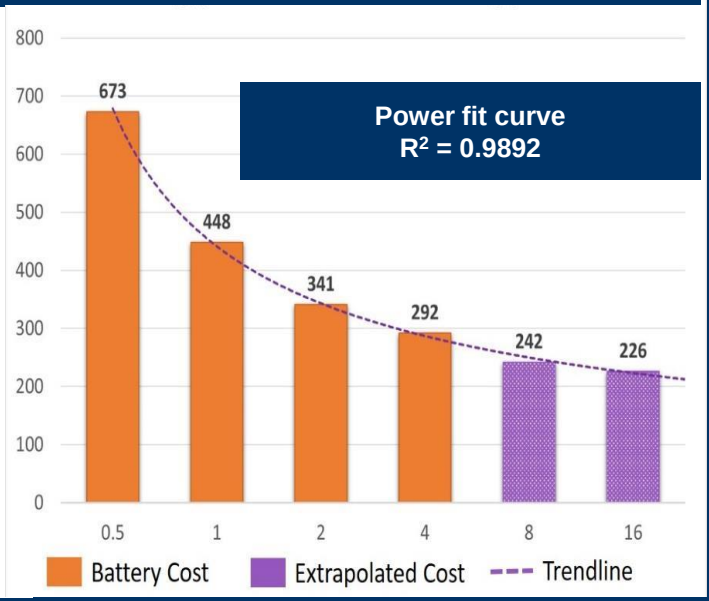
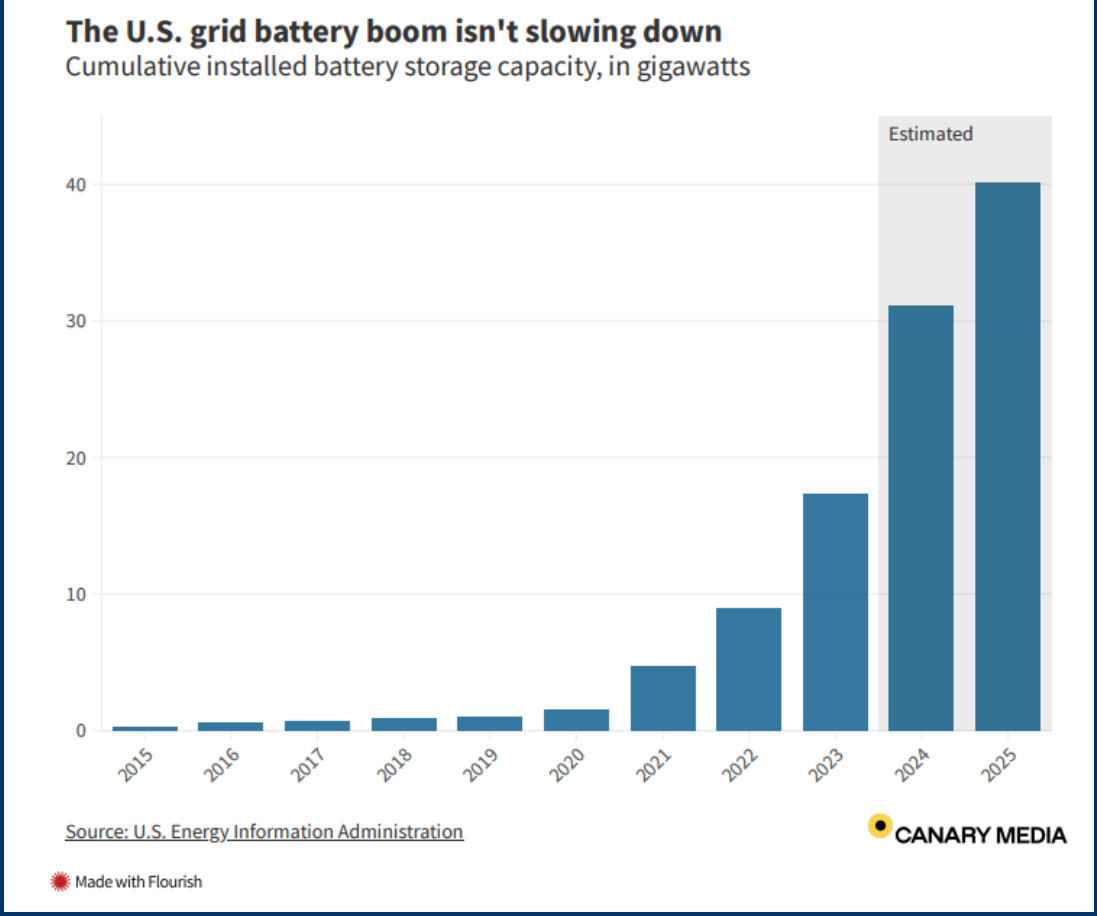


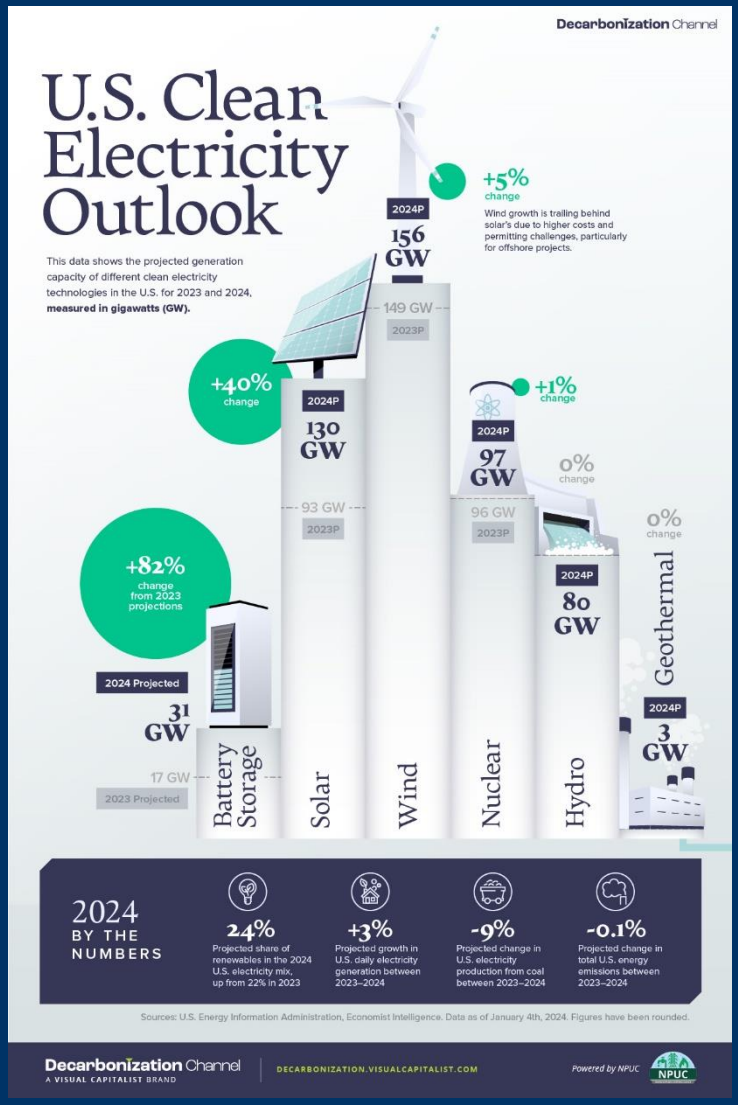
Chart: The US grid battery fleet is about to double — again

America's energy storage industry is on a tear, installing batteries to store clean wind and solar and make the grid more reliable (1-12-2024(



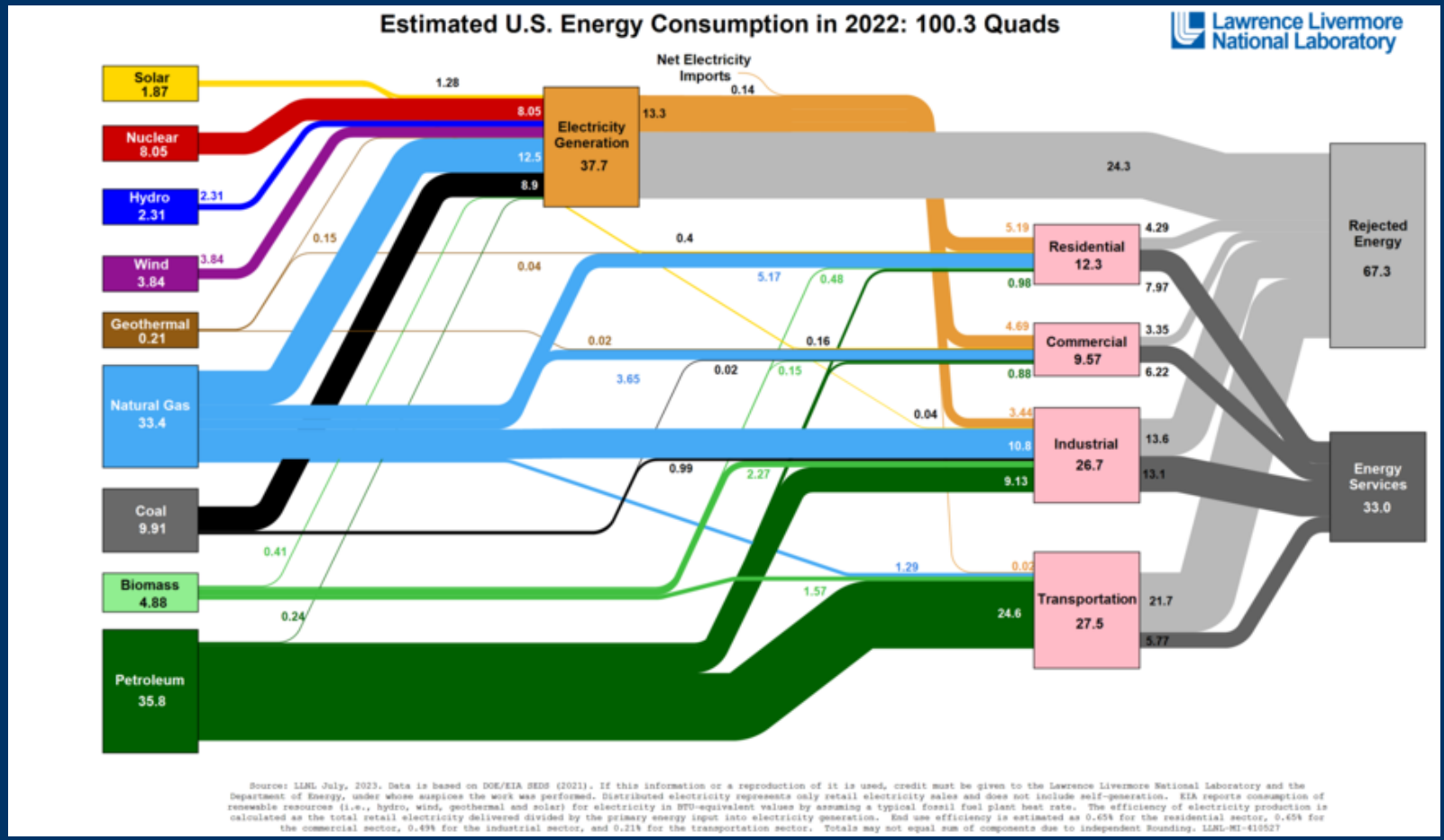
Projected New Power Generation & Storage in US in 2024 (2-1-24)

https://www.visualcapitalist.com/2024-us-clean-electricity-outlook/



PROBLEMS OF EXISTING AC GRID

US Power Flow Chart
https://flowcharts.llnl.gov/



Current State of the Grid

- Working on the Basic concepts developed in the last century
- Northeast blackout of 2003: 55 million People Affected
- 2012 India Blackout: 620 million People Affected
- February 2021: Massive electricity generation failure in the state of Texas, More than 4.5 million of houses and Business without power for several days: At least 246 People were killed
- Get Ready More Blackouts are Coming : March 23, 2023
- https://www.businessinsider.com/blackouts-power-outages-more-common-climate-change-electric-grid-infrastructure-2023-3
- Kenya Suffers Third Major Blackout in 4 months, December 11, 2023
- https://www.nytimes.com/2023/12/11/world/africa/kenya-blackout.html
- The U.S. Electric System Is Leaning on Customers to Avoid Blackouts
- https://www.wsj.com/articles/the-u-s-electric-system-is-leaning-on-customers-to-avoid-blackouts-11668205522
- Ignoring the Basic Understanding that Electric grids fed by free fuel energy sources need a different kind of plumbing
- https://www.economist.com/technology-quarterly/2023/04/05/electric-grids-fed-by-renewables-need-a-different-kind-of-plumbing
- For electrified economy US Utilities Must spend $12 Trillion over 12 years and Electricity prices will increase
- https://oilprice.com/Energy/Energy-General/US-Electric-Utilities-Must-Spend-12-Trillion-To-Reach-Targets.html

EPRI Head: Duck Curve Now Looks Like a Canyon (4-27-2023)

https://www.powermag.com/epri-head-duck-curve-now-looks-like-a-canyon/

- Poland declares threat to electricity supply due to too much renewable energy (4-24-2023)
  - https://notesfrompoland.com/2023/04/24/poland-declares-threat-to-electricity-supply-due-to-too-much-renewable-energy/

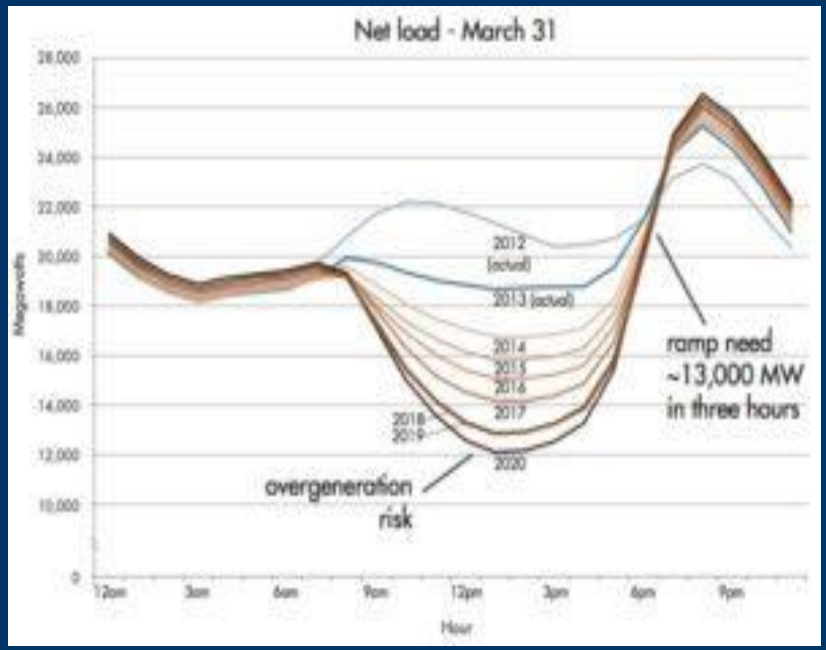
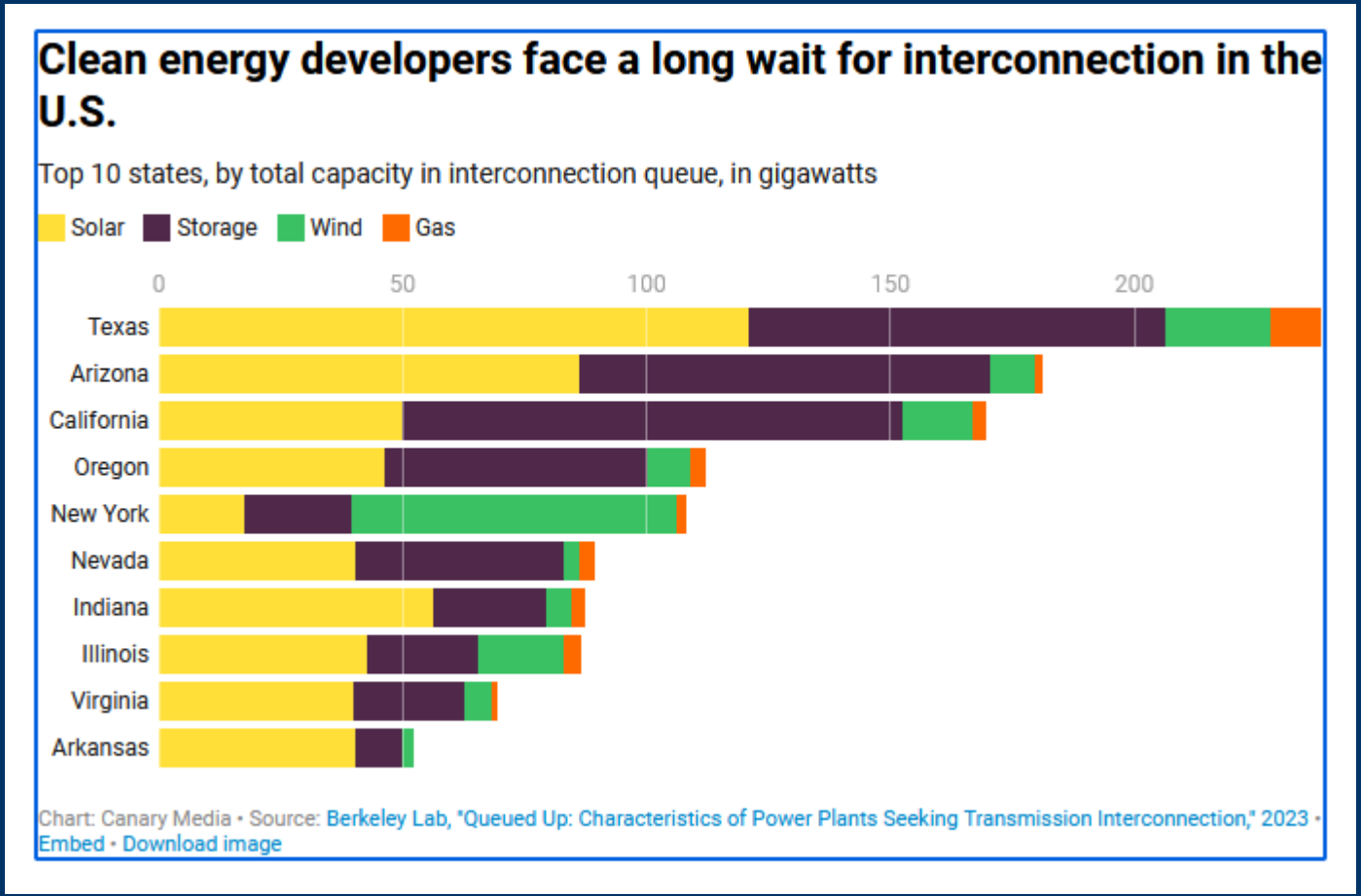


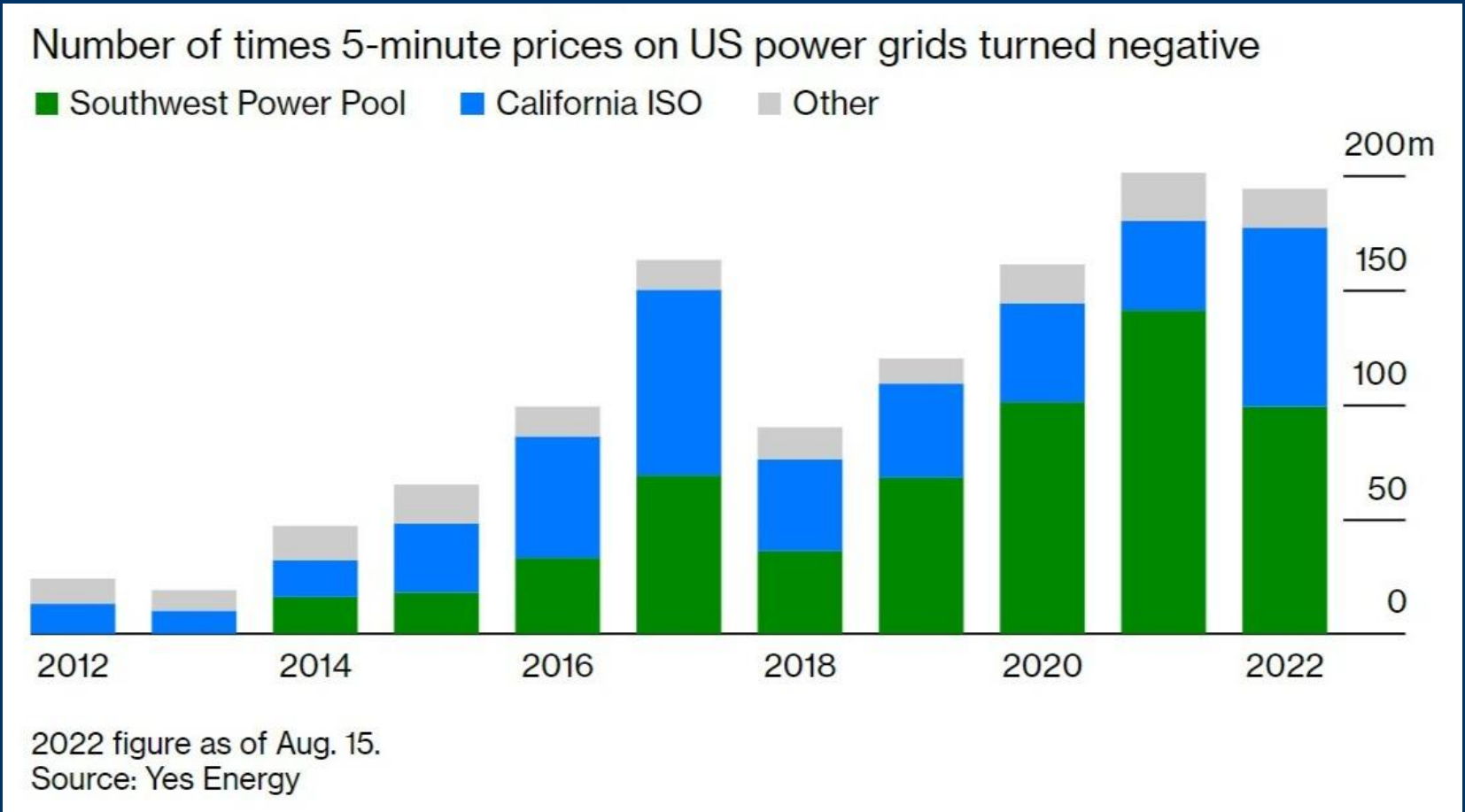
Chart: US clean energy backlog balloons to unprecedented 2 terawatts

https://www.canarymedia.com/articles/clean-energy/chart-us-clean-energy-backlog-balloons-to-unprecedented-2-terawatts



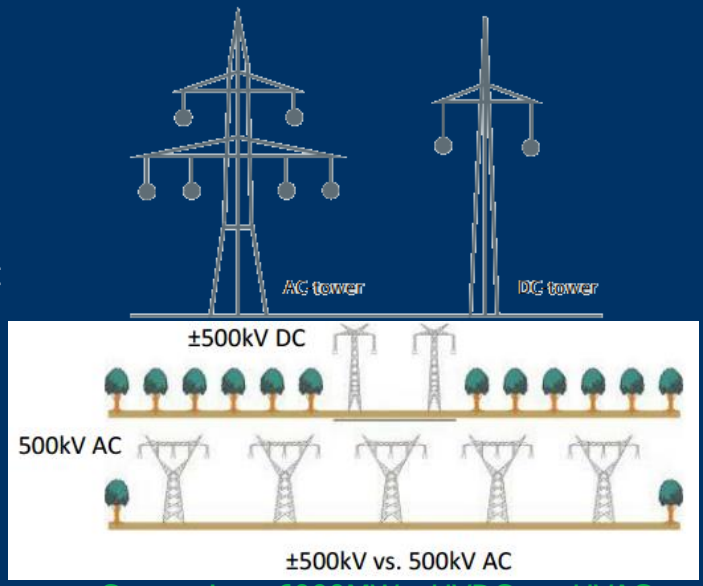
Negative Power Prices? Blame the US Grid for Stranding Renewable Energy (8-30-22)

https://www.bloomberg.com/news/articles/2022-08-30/trapped-renewable-energy-sends-us-power-prices-below-zero#xj4y7vzkg

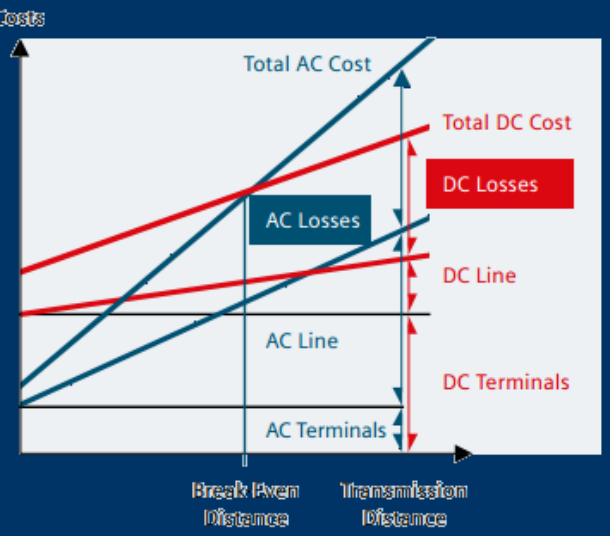


Advantages of HVDC Systems

- **Major advantage of flexibility in power exchange in comparison with HVAC**
  - Fast control of power flow – practically independently from frequency, voltage or angle at terminal buses
  - Fast change of direction of transmitted power – due to inherent properties of the electronic equipment in converters
  - Controllable – power injected where needed, supplemental control, frequency control
- **Bypass congested circuits – no inadvertent flow**
- **Lower losses**
- **Reactive power demand limited to terminals independent of distances**
- **Narrow Right-of-Way (RoW) –**
  - land coverage and the associated right-of-way cost for an HVDC overhead transmission line is smaller,
  - reduced visual impact
  - higher power transmission capacity for same RoW
- **no Electromagnetic field (EMF) constraints**
- **Cost Comparison HVDC vs. HVAC**
  - HVDC has a higher installation cost due to the converter stations and filtering requirement
  - The cost of an HVDC line is less than the cost of an AC line. Long AC lines are more expensive due to shunt and series compensation requirements



Comparison 6000MW - HVDC vs. HVAC

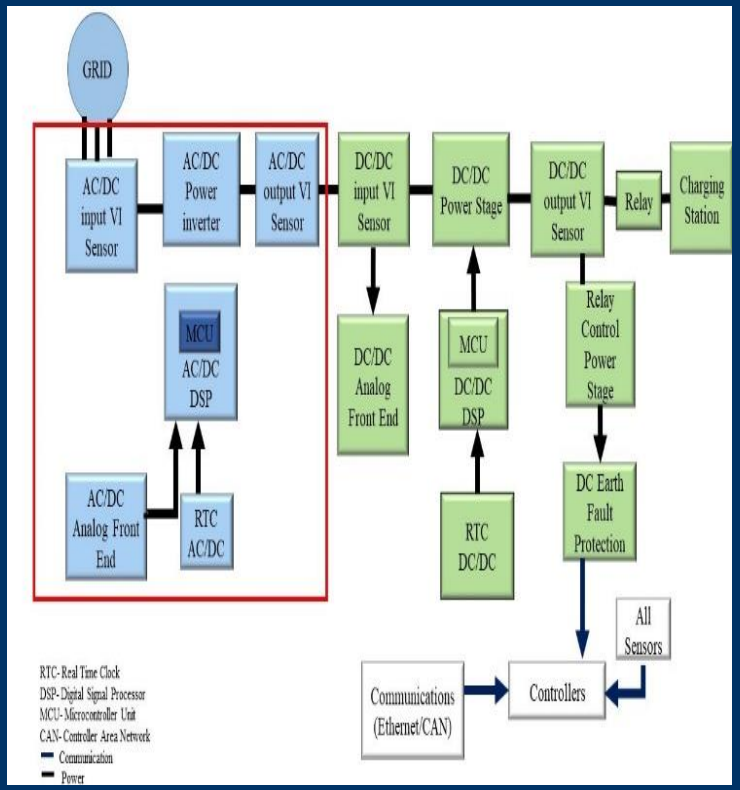


Advantage of DC Over AC Power Systems

- Increased power transfer
- Reduced line losses
- Improved system stability and efficiency by ease of power flow control and decreased power quality concerns.
- Elimination of frequency and phase mismatch faults and ease of islanding capability to prevent cascading failures.
- Ease of integration of DC generation with DERs and evolving modern DC loads like
- Reduced Right-of-Way (RoW) for pylons and transmission towers.
- Smaller system footprints by using high power density components and devices for DC-DC voltage conversion.
- Higher system reliability due to lower number of components, as well as modular and scalable power electronics converters.
- Reduced surface area for cyber-attacks, and
- Reduced capital costs of infrastructure by avoiding bulky rotating turbine masses.

21st Century Reality

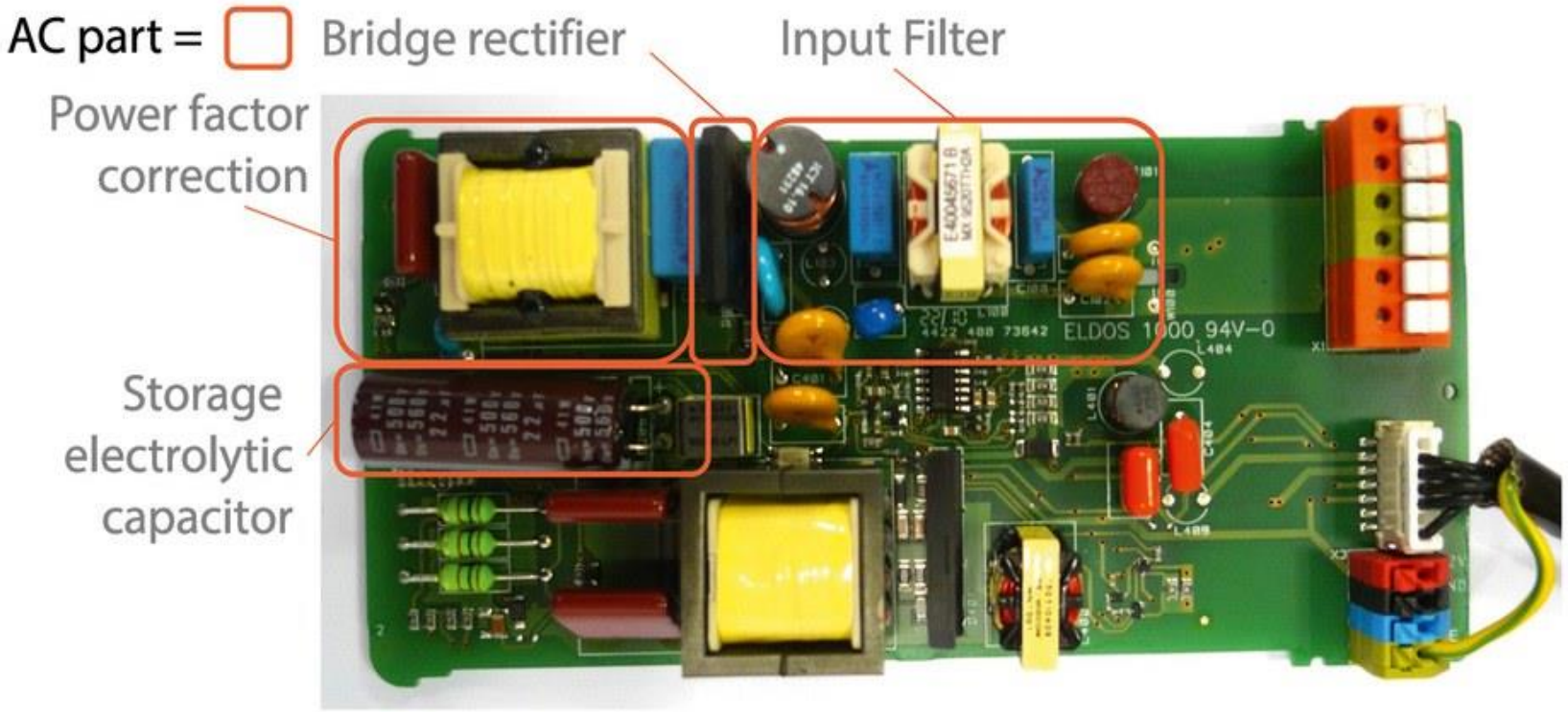
- Photovoltaics Generates DC Power
- Batteries , and Fuel Cells store DC Power
- Except few Inductive loads, all our loads today requires DC power as the Input Power
- DC Fast Chargers need input DC power
- Baseload Concept must be ignored
- We are still using AC infrastructure in the 21st century
- We are wasting large amount of Electric power by using AC infrastructure rather than DC infrastructure
- Capital cost of Loads is high due to internal conversion (AC to DC)



Power driver for a 35W LED lamp. All parts that are necessary for AC to DC conversion are marked Red

https://www.led-professional.com/resources-1/articles/direct-current-dc-supply-grids-for-led-lighting

LOWER CAPITAL COST, HIGHER RELIABILITY, BETTER CYBER SECURITY DUE TO LOWER ATTACK SURFACE AREA



LIMITATIONS OF AC GRID

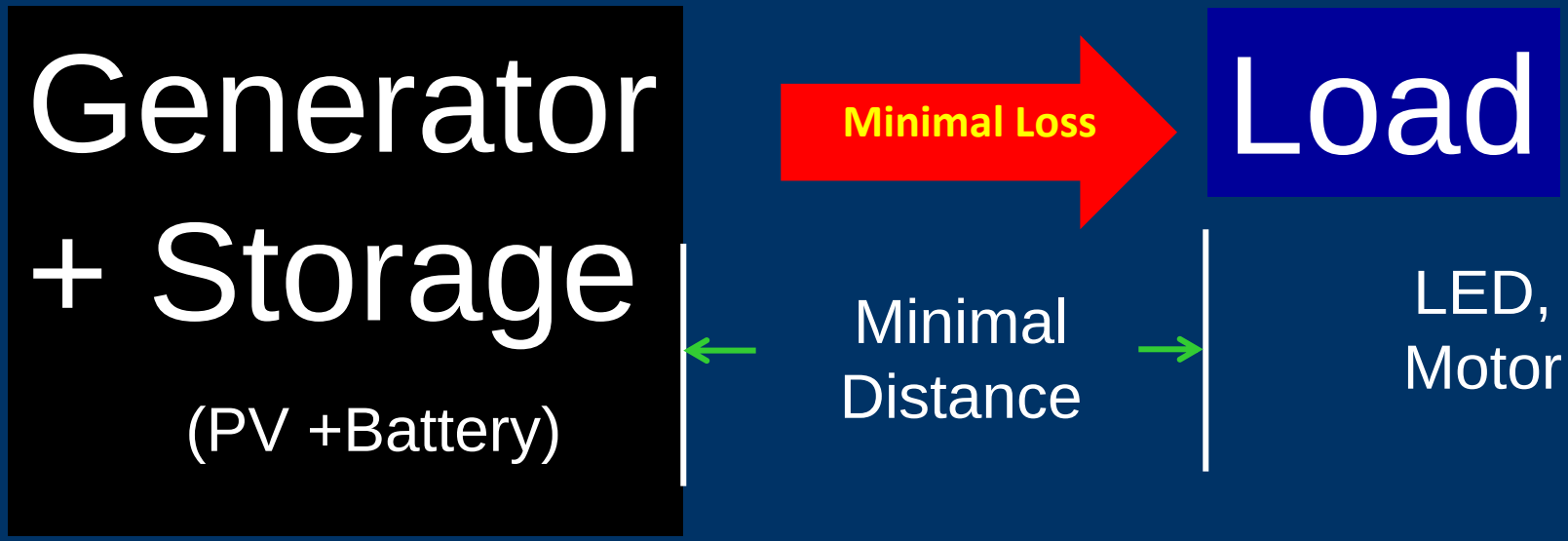
- **AC Power in the world of today is like buying a glass of coke or bear and not drinking Froth, but you have to pay**
- DC systems offer advantages such as higher system energy efficiency, simplified control, high power quality, and better stability due to the absence of synchronization, reactive power, frequency control, skin effect, and harmonic issues associated with AC grids.

Future Solution: End to End DC Power Networks (Thinking Thomas Edison is Alive)

Paradigm Shift: Local LVDC Power(<1,500 V)

R. Singh and K. Shenai

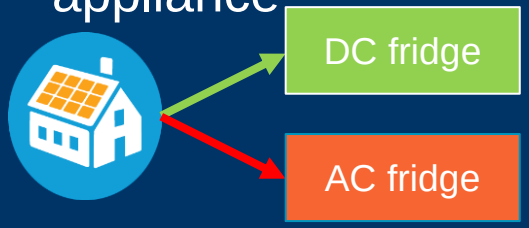
lhttp://spectrum.ieee.org/green-tech/buildings/dc-microgrids-and-the-virtues-of-local-electricityEEE Spectrum



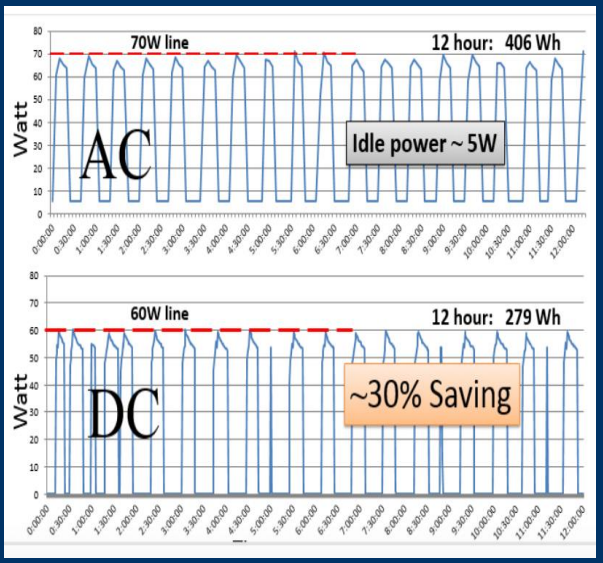
- **Minimum Conversion**
- **DC Power**
- **Maximum Efficiency**
- **AC Operated Load: Provide Built in Inverter**

Experimental data

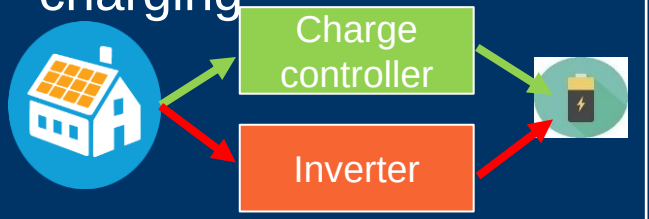
- DC vs AC appliance



- 320 W Rooftop panel
- Morningstar 12V inverter
- Grape Solar dual-mode fridge



- DC vs AC battery charging

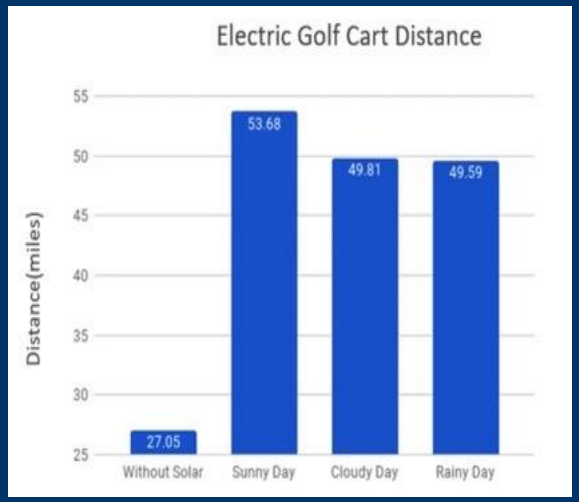


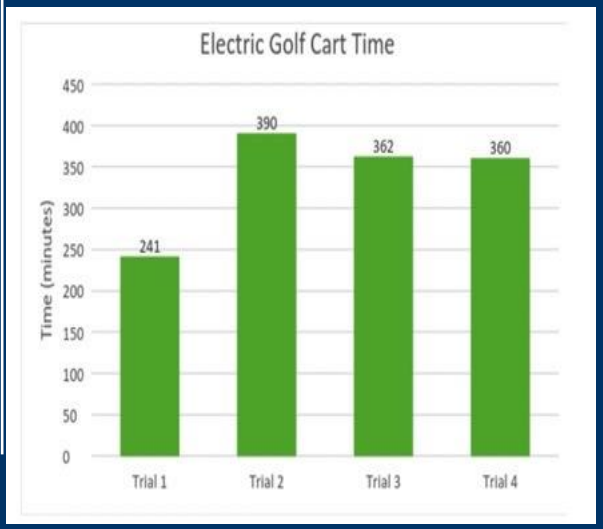
- $LiFePO_4$ battery (15 V)
- TriStar MPPT charge controller
- 30-minute readings at 1-minute intervals

Table 1 DC vs AC Charging efficiency

Parameters	Power Calculations		
	Average input power (W)	Average output power (W)	Average Power Loss (W)
DC Power (W) (Before Absorption State)	43.2	39.375	3.825
DC Power (W) (After Absorption State)	20.31	17.44	2.87
AC Power (W)	154.79	121.66	33.13

- On-board PV for golf cart





As Founding Technical Chair Started a New DC conference , USA

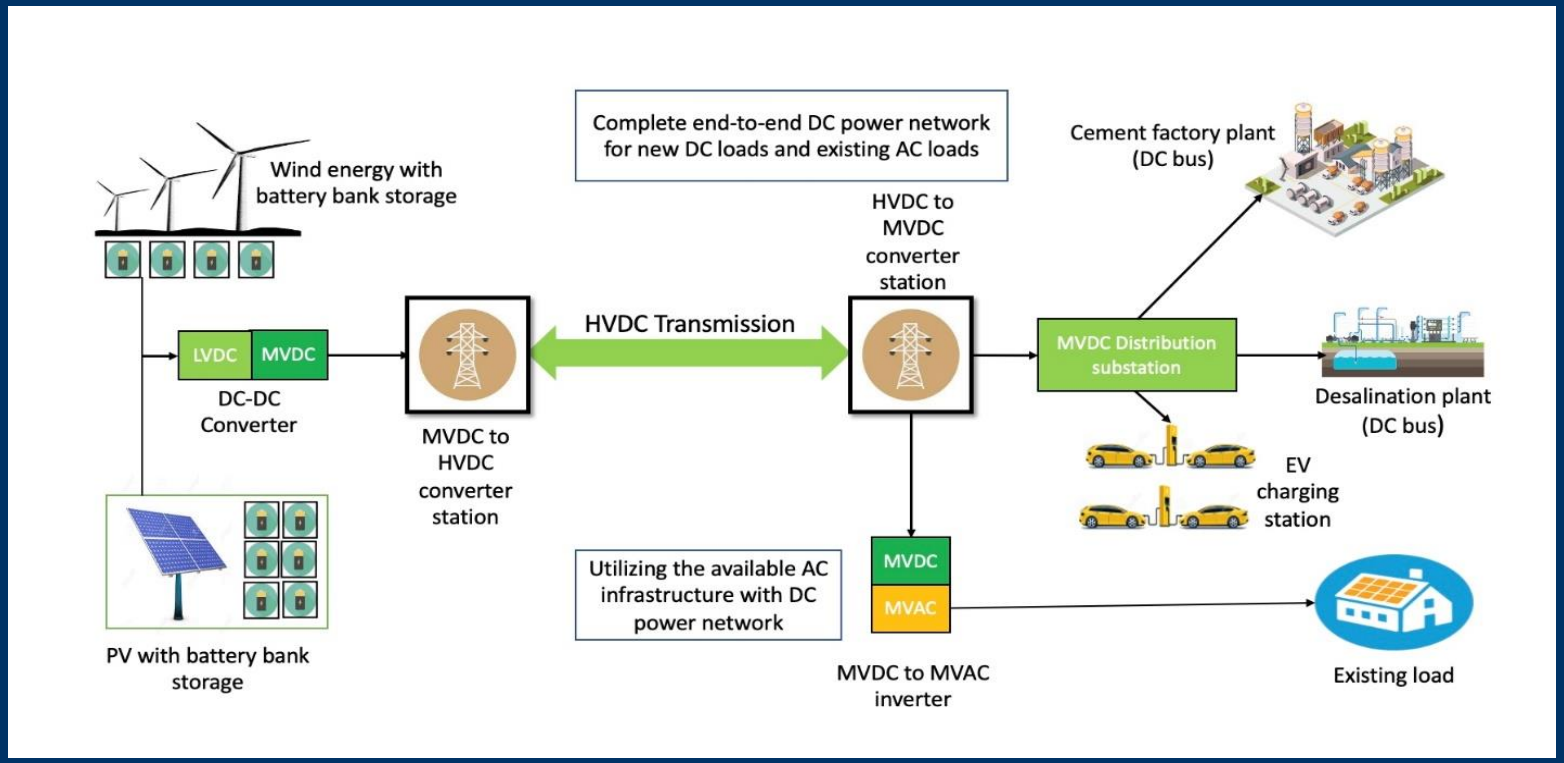
- Welcome," *2015 IEEE First International Conference on DC Microgrids (ICDCM)*, Atlanta, GA, USA, 2015, pp. 1-2, doi: 10.1109/ICDCM.2015.7151991
- As the founding Technical Chair, it gives me great pleasure to welcome you to the First IEEE International Conference on Direct Current Microgrids (ICDCM), This conference is dedicated to memory of Thomas Alva Edison, one of the great visionary of all times,

PV and Battery as Power Source and Storage

- PV = 1,500 V LVDC
- MVDC: 2 kV-50 kV
- HVDC: 50 kV -1,100 kV
- Lot of Progress has been made in case of LVDC based on PV and Batteries. For Limitation of time I will not get into details

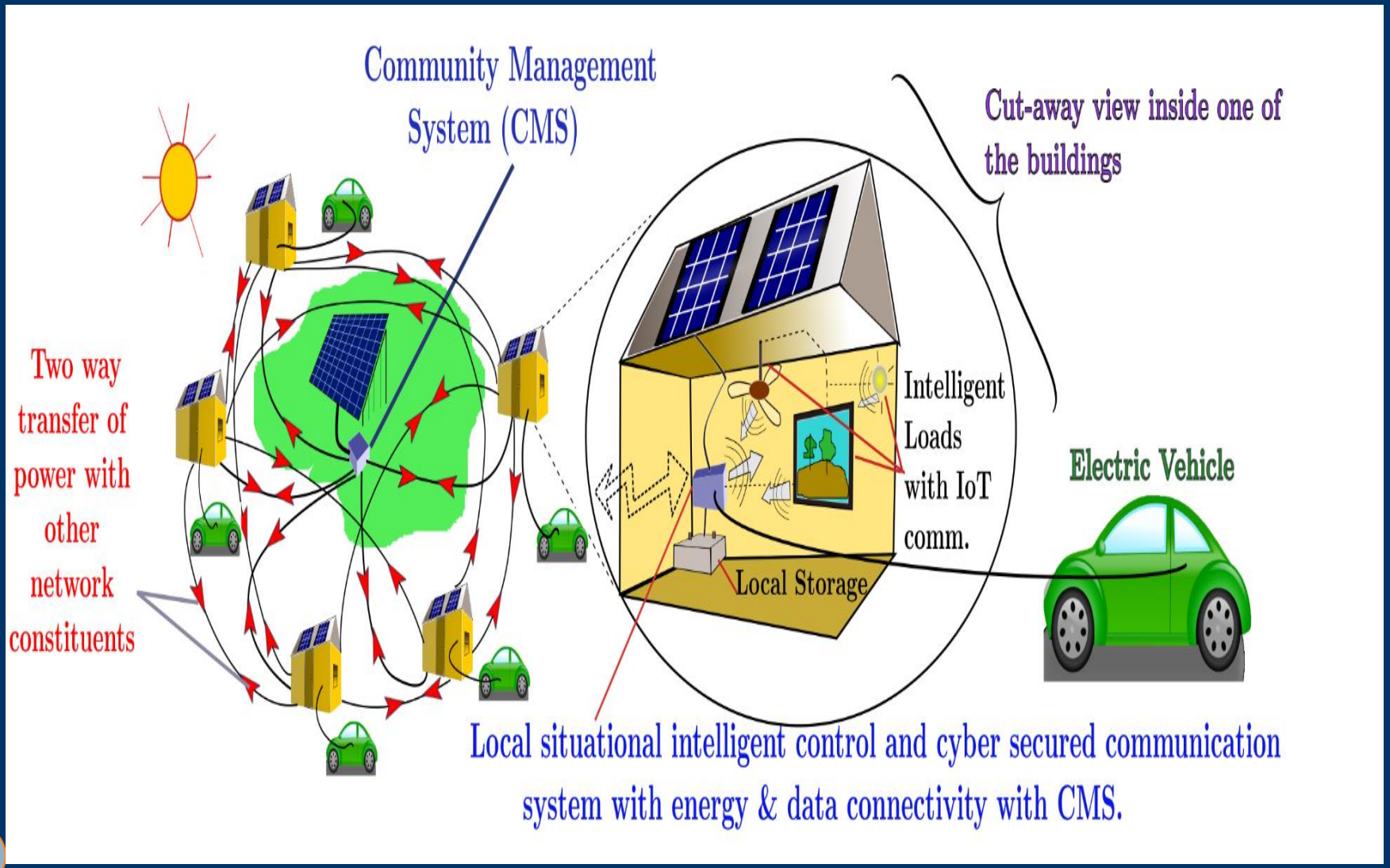
Universal Sustainable Power for All

R. Singh, P. Paniyil and Z. Zhang, "Transformative Role of Power Electronics: In solving climate emergency," in *IEEE Power Electronics Magazine*, vol. 9, no. 2, pp. 39-47, June 2022, doi: 10.1109/MPEL.2022.3169317.



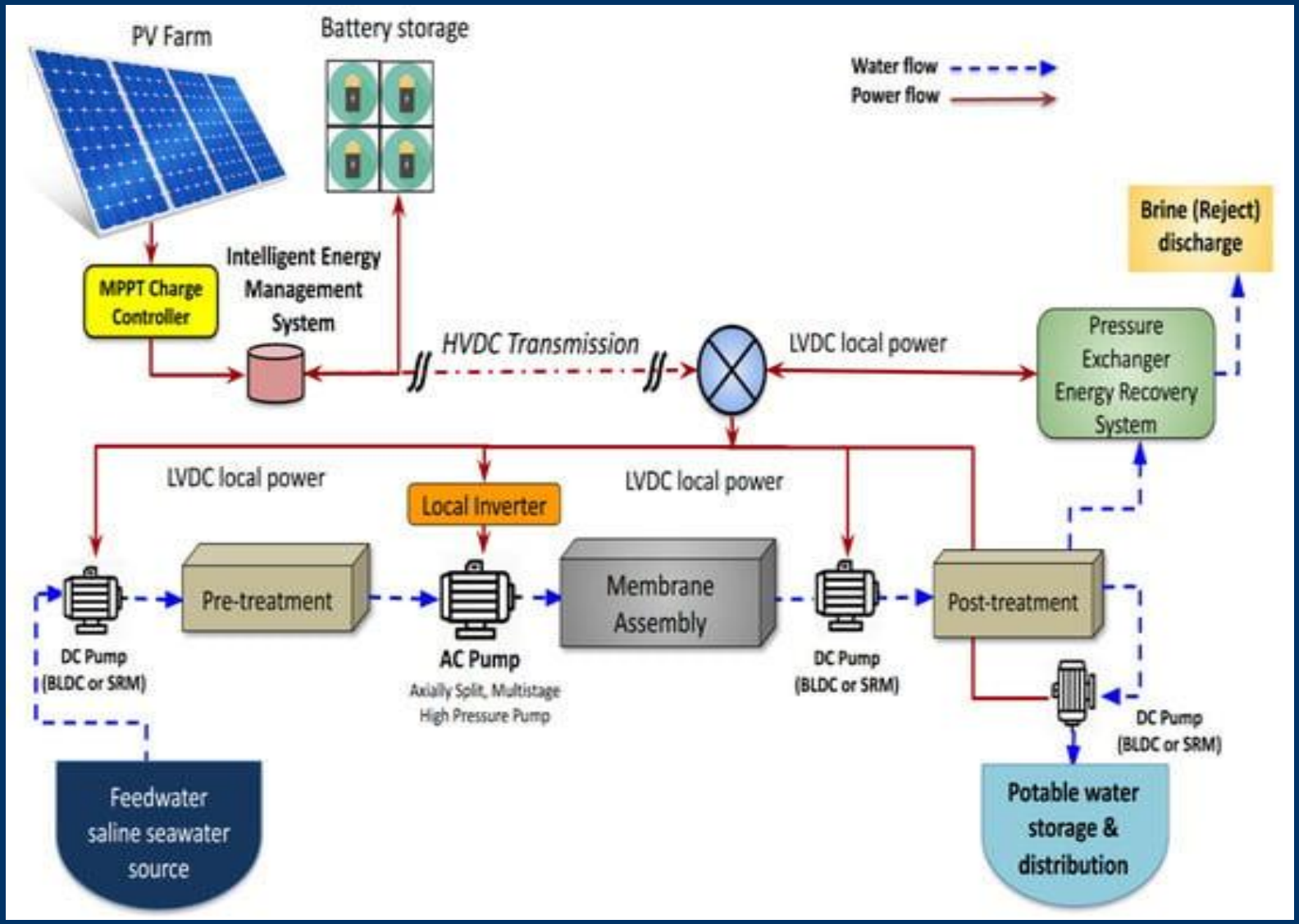
DC Power Network

(Cyber Security, EMP, solar Flare Advantages, lower capital investment, highest energy efficiency) IEEE PVSC 2016

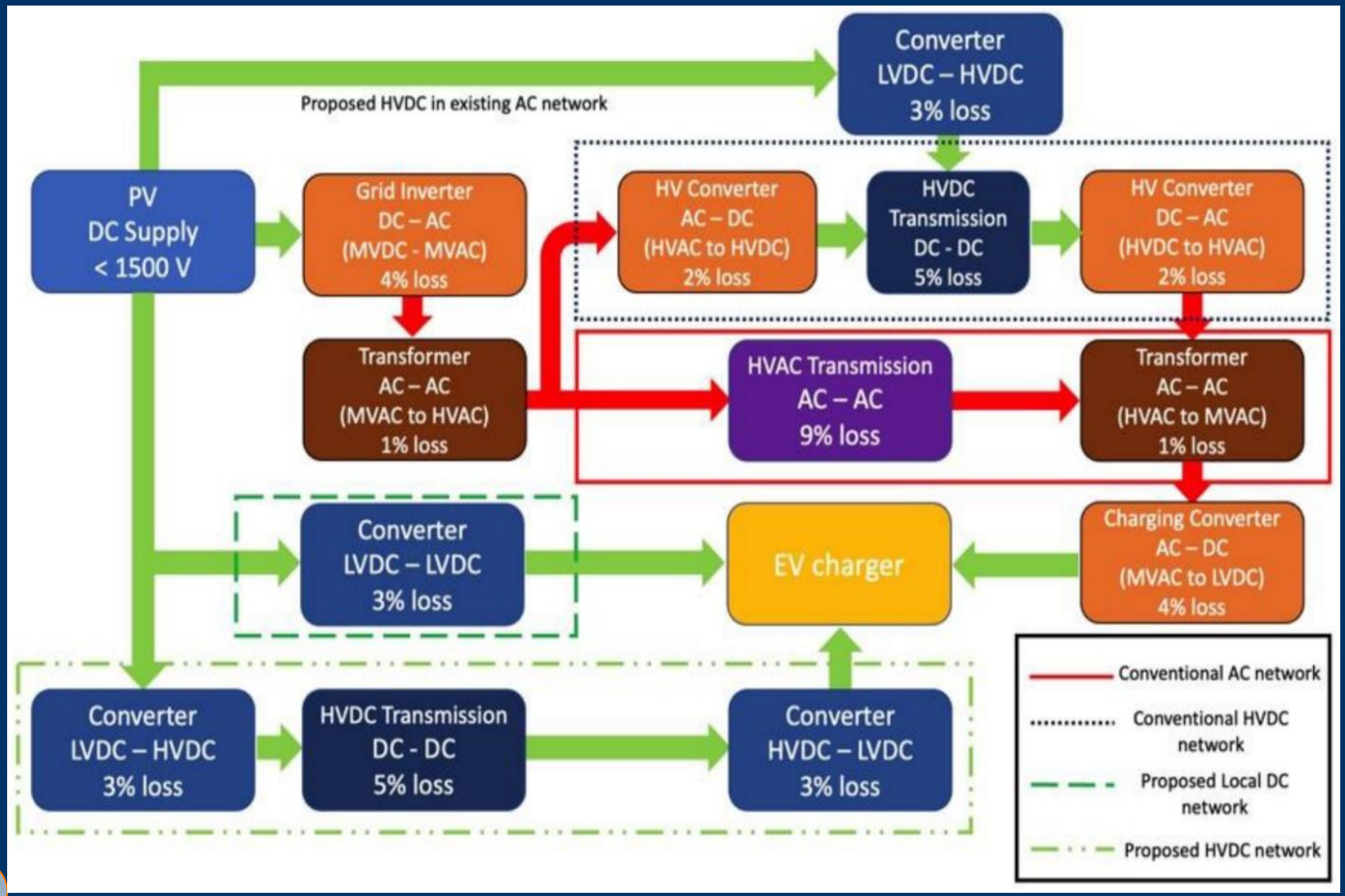


No Concept of Base Load: Proposed Desalination Power Plant Design

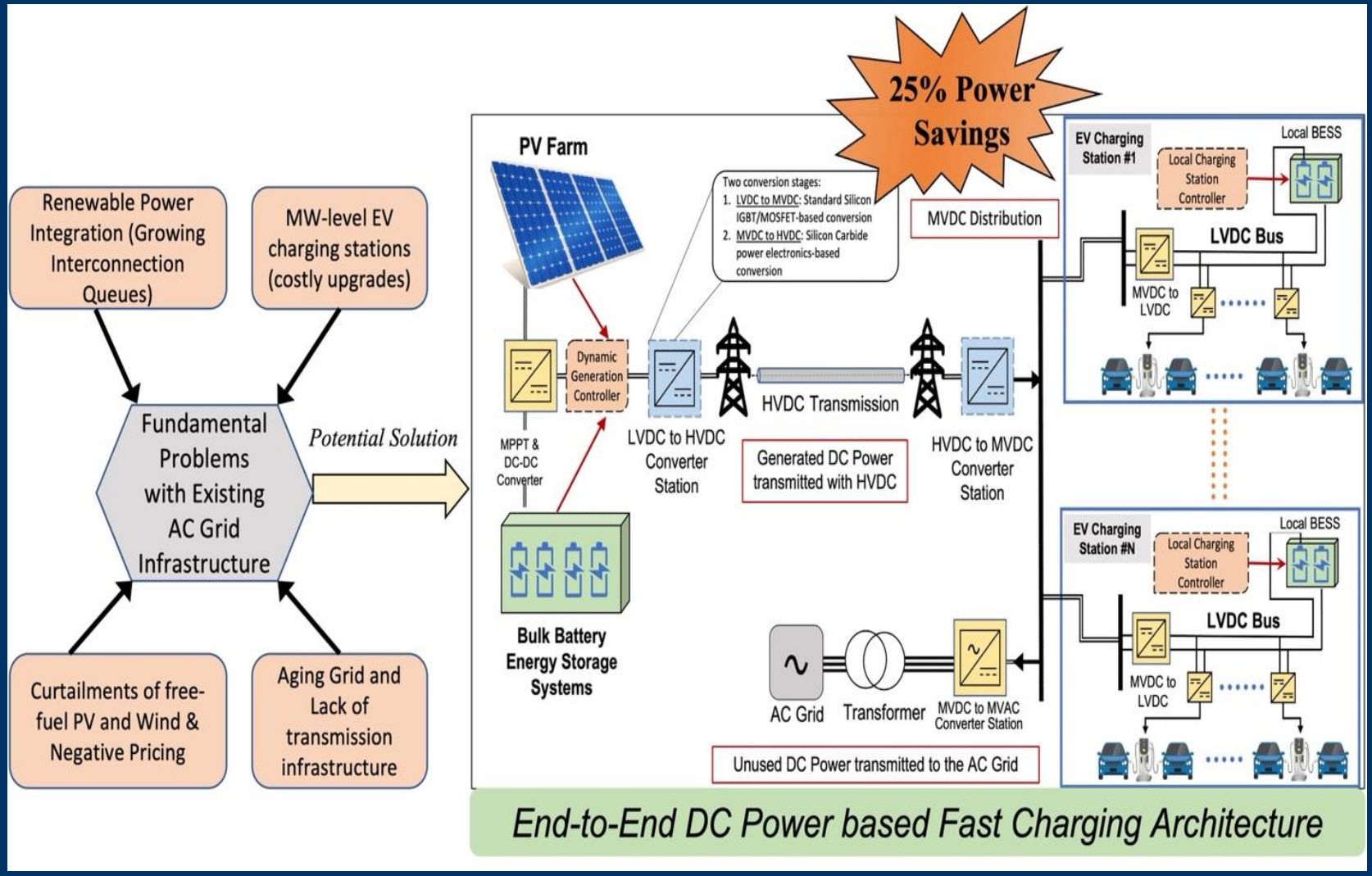
https://www.mdpi.com/1996-1073/14/10/2772



Power losses in conventional AC grid and proposed Power Networks



Practical Application that can be Implemented today https://www.mdpi.com/2313-0105/9/3/169



On Board Local DC Power Network

- ABB built a ship working on local DC Power (1,000 V, 20 MW power)
- 20 % Energy Savings
- 30 % Foot Print and Weight Reduction
- http://www05.abb.com/global/scot/scot293.nsf/veritydisplay/b4f3f099e9d21360c1257a8a003beac2/$file/ABB%20Generations_20%20Onboard%20DC%20grid.pdf

Under Water Long Haul Transmission of Power

- Europe, Singapore: Limitations of Land
- Africa, Australia: Green Power Generation

The World's Longest Sub-sea Cable will send Green Electric Power from Morocco to UK (April 21,2022)

- The project will cost $21.9 billion. Xlinks will construct 7 GW of solar and 3.5 GW of wind, along with onsite 20GWh/5GW battery storage, in Morocco.
- https://electrek.co/2022/10/06/first-clean-energy-plant-opens-using-solar-wind-battery-storage/

Morocco-UK Xlinks Project: Vegar Larsen New to Lead $1.4 Billion Cable Plant (2-13-24)

- The manufacturing of the underwater cables for the Morocco-UK Xlinks Project will begin in early 2024
- https://www.moroccoworldnews.com/2024/02/360790/morocco-uk-xlinks-project-vegar-larsen-new-to-lead-1-4-billion-cable-plant

Transformative Roles

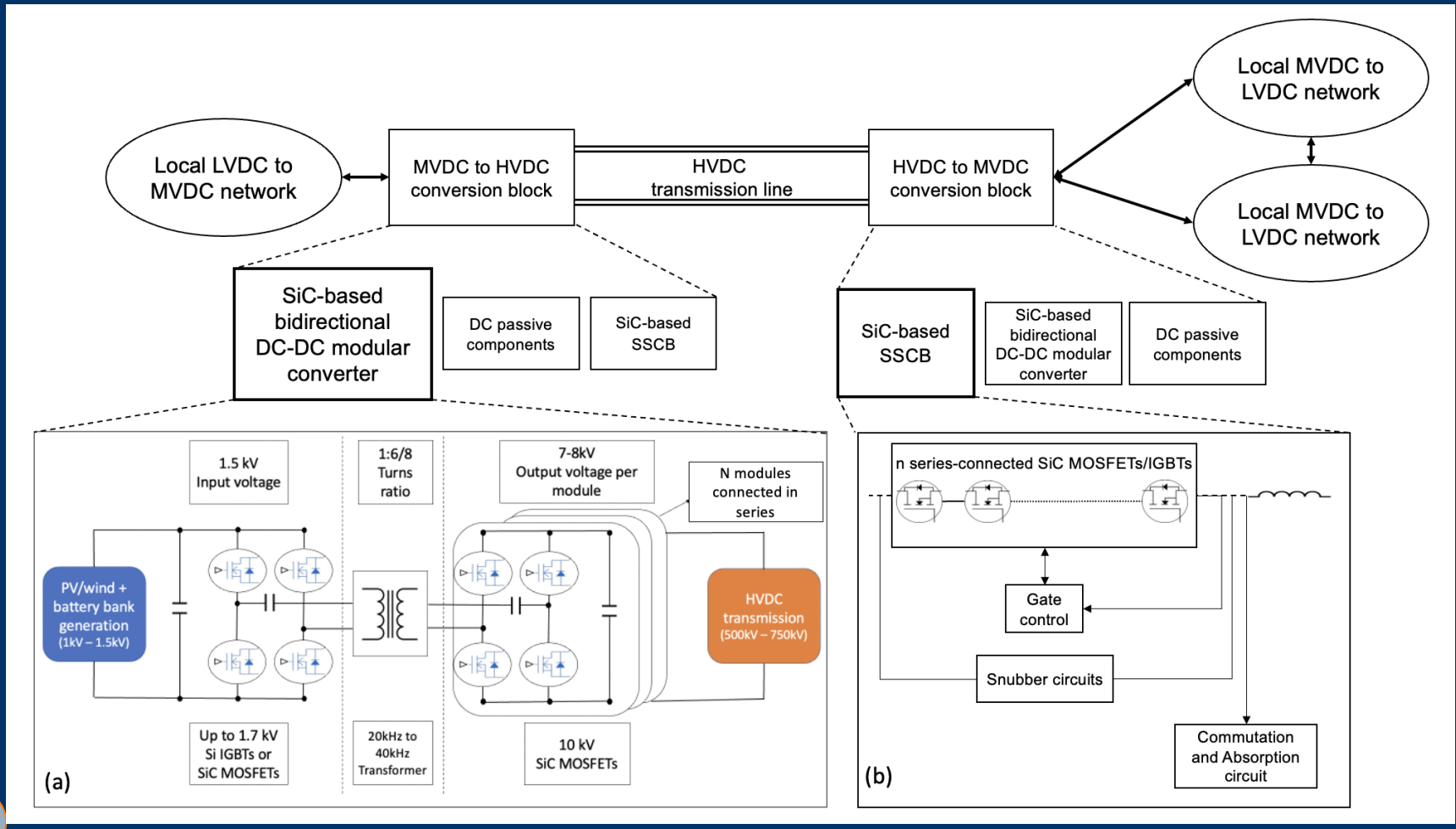
Device	Sector	Remark
Silicon (CMOS)	Information Technology	About 92- 95% of electronics worth $1.5trillion is based on CMOS technology
Silicon PV system	Power generation	Free fuel ~ 1,000 M (1 TW)W installations mid 2022, 2 TW by 2025
Lithium ion battery	Energy storage	~$100/kWh, nearing cheaper than Hydro Cost

Challenging Opportunities

- Solid State Bi-Directional MVDC to HVDC and LVDC to MVDC converters
- AI Based Power flow Controllers
- End to End DC applications without considering the concept of baseload
- Intelligent loads with cyber secured IoT
- R. Singh, P. Paniyil and Z. Zhang, "Transformative Role of Power Electronics: In solving climate emergency", in IEEE Power Electronics Magazine, vol. 9, no. 2, pp. 39-47, June 2022, doi: 10.1109/MPEL.2022.3169317.

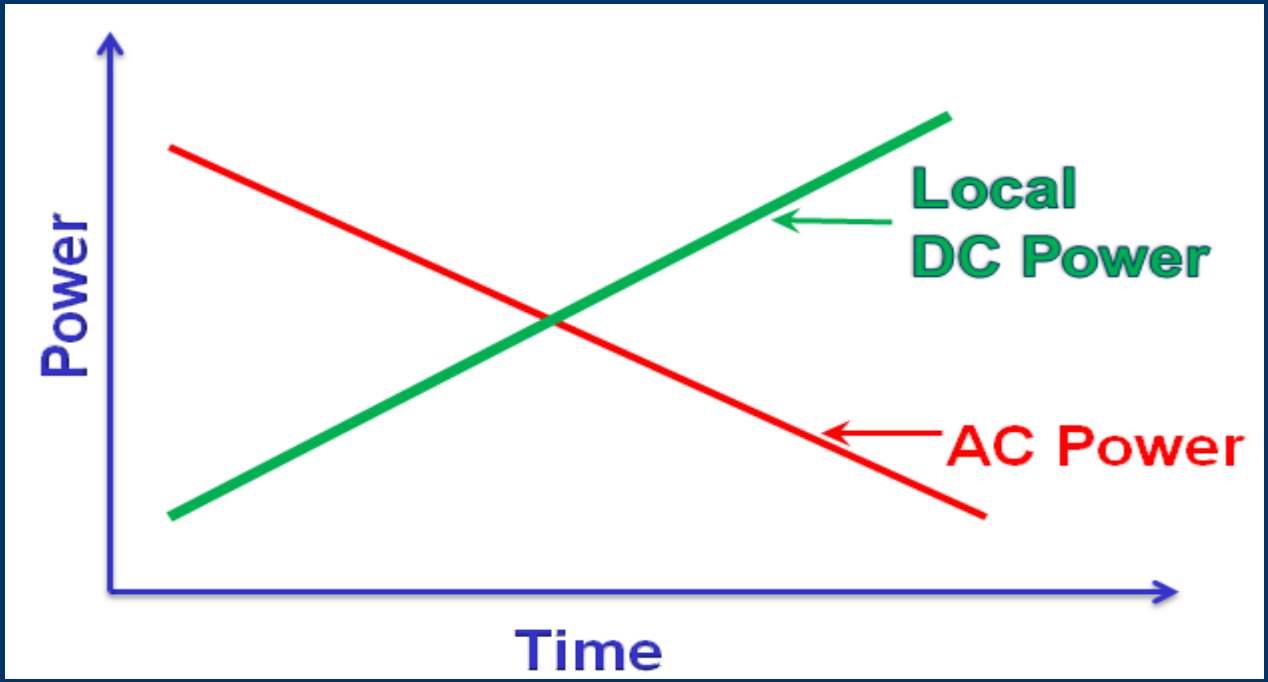
DC power network with HVDC transmission enabled by SiC-based DC-DC converter and SSCB. (a) Bidirectional soft switching resonant MVDC-HVDC converter concept (b) Solid state Circuit Breaker for HVDC operation

R. Singh et al. IEEE PES Magazine (In Review)



Dept. of HVDC and Power Electronics Technology,
Electric Power Research Institute of CSG, P. R. China

Public Policy: Phase Out AC Power & Replace by Local DC Power Network of PV, Wind and Batteries



Stress on Fundamentals

R. Singh, “Technical and Economical Assessment of Photovoltaics for Rural Development in Developing Countries”, Int. Journal of Energy Systems, vol. 1. No. 3. pp. 209-212, 1981

Since the PV system can be located on site, the laying cost of transmission and distribution can be saved. (LOCAL DC POWER NETWORK)

Conclusion: Out of the various matured technologies, flat plate panel Si PV systems are economically feasible. Si will be dominating PV material in the sheet or amorphous thin film for coming years. (More than 95 % PV market is Based on Si PV Modules)

Large Scale production (~250 MW/year) by automated solar cell factories will cut the cost of solar cells drastically. (Key Driver of Ultra Low cost of PV Electrical Power is Ultra large Scale Manufacturing)

Key Note Talk: 2012 International Conference on Emerging Electronics , IIT Bombay, December 2012

Green Energy Conversion & Storage for Solving India's Energy Problem through Innovation in Ultra Large Scale Manufacturing and Advanced Research of Solid State Devices and Systems

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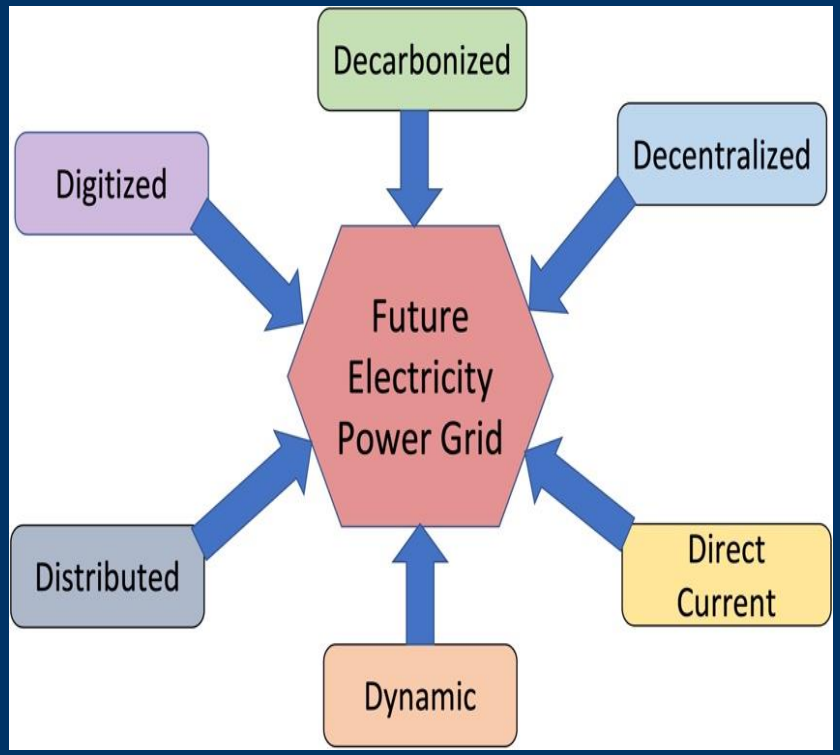
***Abstract*— The shortage of cheap and abundant energy in India is currently a major roadblock in achieving higher economic growth. Free fuel based solar and wind energy sources can provide sustained economic growth. Lack of understanding regarding the role of photovoltaics (PV) as a major current and future energy conversion technology by policy makers and top businessmen in India is a fundamental roadblock in the large scale implementation of PV. With major innovations in energy policy, large scale manufacturing of PV modules and related systems in India, and the use of a vertically integrated business model, PV electricity can be generated at the cost of Rs. 5/kWh in India today. In addition to novel applications of PV in transport sector and water lifting for irrigation and drinking, appropriate research directions in solid-state energy conversion and storage devices (solar cells, inverters, light emitting diodes, thermoelectric devices, and solid-state capacitors) and related systems are presented.**

solid-state devices in global green energy conversion revolution in the 21st century [7]. Globally photovoltaic is the fastest growing industry in energy sector. Unfortunately, the policy makers and top businessmen in India do not understand the current and future importance of solid state devices and related systems in energy conversion. The purpose of this paper is to highlight the importance of photovoltaic (PV) devices and systems that can change the landscape of electricity generation in India today. The light emitting diodes have the potential of playing a major role in near future. In addition, we have also pointed out the important advanced research directions in thermoelectric devices and solid-state capacitors (energy storage) that can pay important dividends in overall energy scenario in India.

II. Energy Policy And Related Issues

CONCLUSIONS

- AC grid will be phased out by end to end DC networks in a way similar to the replacement of incandescent light bulb by LED.
- As compared to the concept of smart grid , our proposed end to end DC network provides two additional features pf DC power and dynamic control.
-



We are Sitting at the Tip of the Iceberg

https://www.google.com/search?q=We+are+Sitting+at+the+Tip+of+the+Iceberg&client=firefox-a&hs=i2S&rls=org.mozilla:en

Thank You.
Questions?