CSP and CPV – Opportunities & Issues

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October 2008
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not your niche markets anymore!

The New Green

The Markets You Think Of

- Engines ($200B)
- Lighting ($80B - US)
- Appliances ($10's B+)
- Batteries + Flow Cells ($50B +)
- Gasoline ($500B+)
- Diesel ($500B+)
- Jet Fuel ($100B+)

- Corn Ethanol
- Biodiesel
- Solar PV
- Wind
- Geothermal

- Cement ($100B+)
- Water ($500B+)
- Glass ($40B)
- Home Building (!!!)
- BioPlastics ($10's B+)

Power Generation ($250B – US)

- Solar Thermal
- EGS
- Clean Coal
- New Nukes

…”relevant cost”
…”relevant scale”
…”relevant adoption”

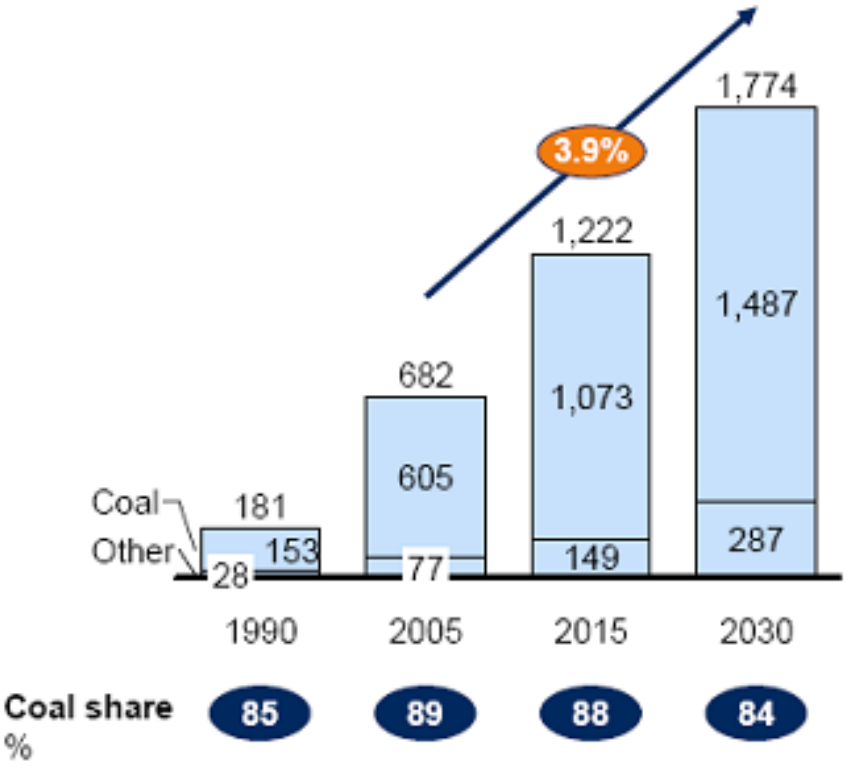
…the chindia price

competitive unsubsidized

without alternatives, coal use will increase

COAL WILL FUEL MOST OF THE RAPID GROWTH IN CHINA'S POWER SECTOR

Energy demand in power sector, millions of tons of oil equivalent per year



Source: McKinsey

1990: Chindia ≈ 13% of CO_2 emissions

2005: Chindia ≈ 23% of CO_2 emissions

2030: Chindia ≈ 34% of CO_2 emissions

EIA

…the scaling model

brute force or exponential, distributed…

…the adoption risk

financial, consumer acceptance, market entry

…"relevant scale" solutions for

… coal

… oil

… materials

… efficiency

Khosla Ventures' rules of investing

Attack manageable but material problems

Technology that achieves unsubsidized competitiveness

Technology that scales - if it isn't cheaper it doesn't scale

Manageable startup costs & short innovation cycles

Declining cost with scale – trajectory matters

…technology expands the “Art of the Possible”

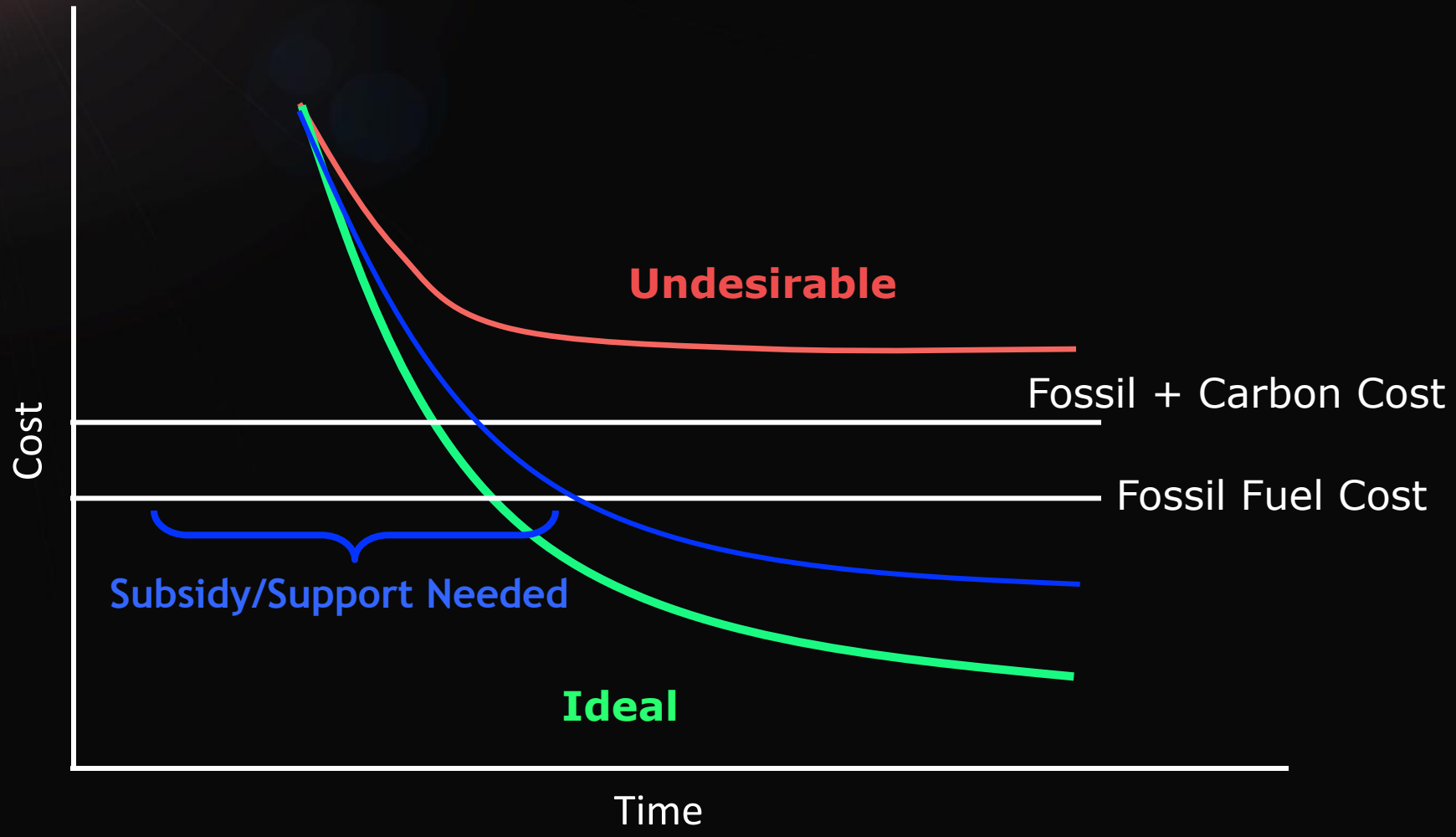
to predict the future, invent it!

…today’s “unimaginable” is tomorrow’s “conventional wisdom”

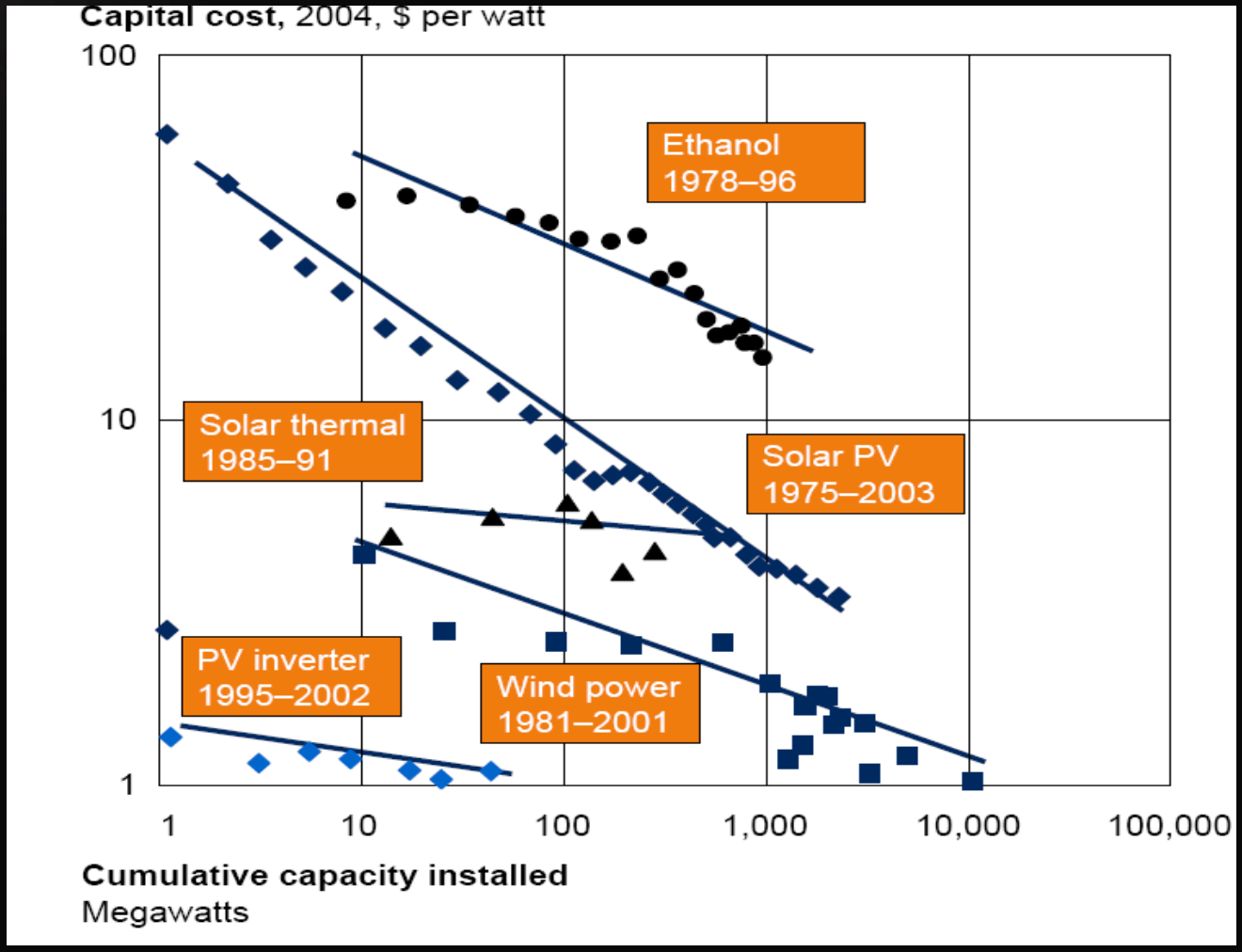
key criteria

- Trajectory: “What is” or “What Can Be”
  - Cost Trajectory
  - Scalability Trajectory
- Adoption Risk
- Capital Formation
- Optionality

cost: new technologies require time…



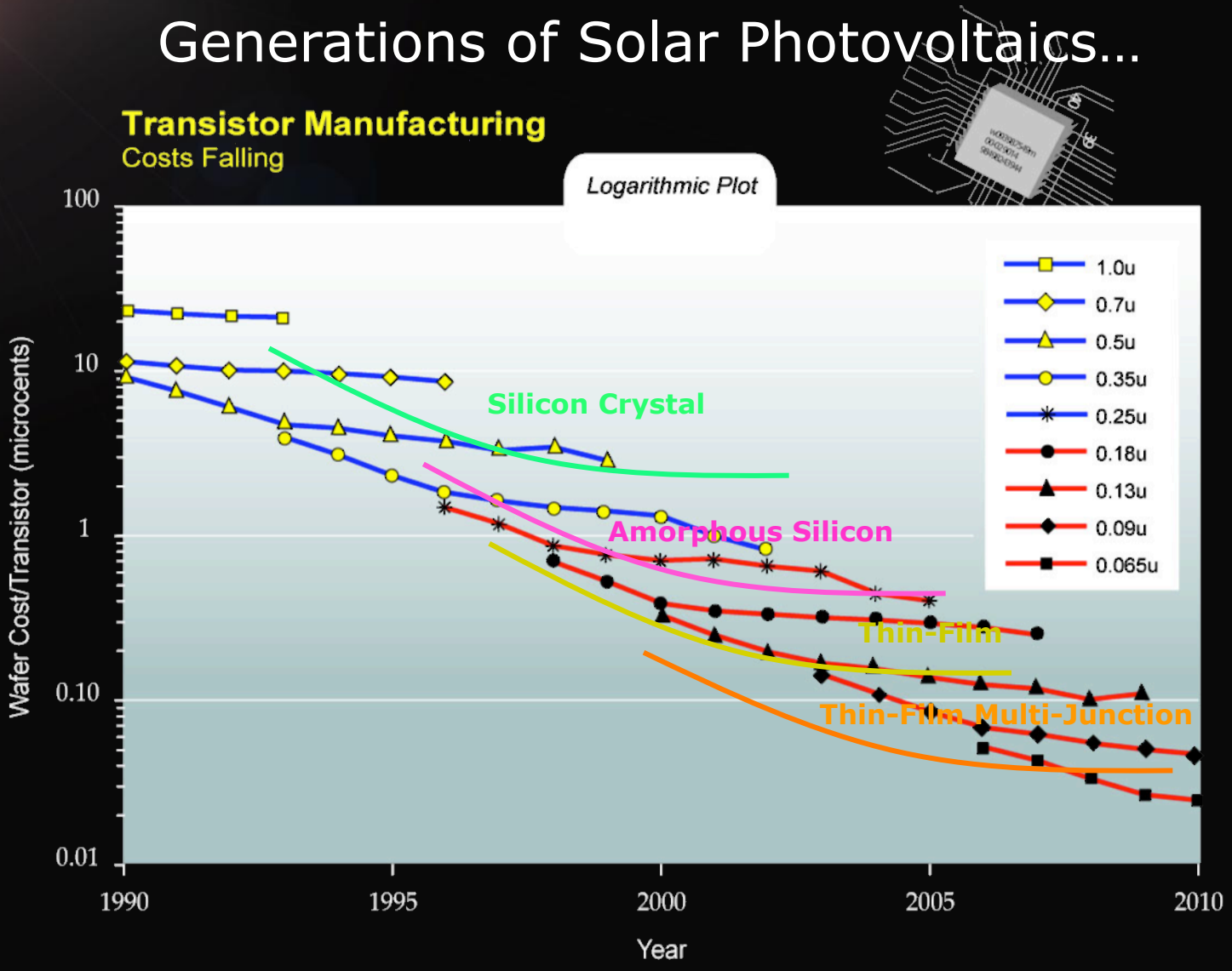
cost: driving down the cost curve



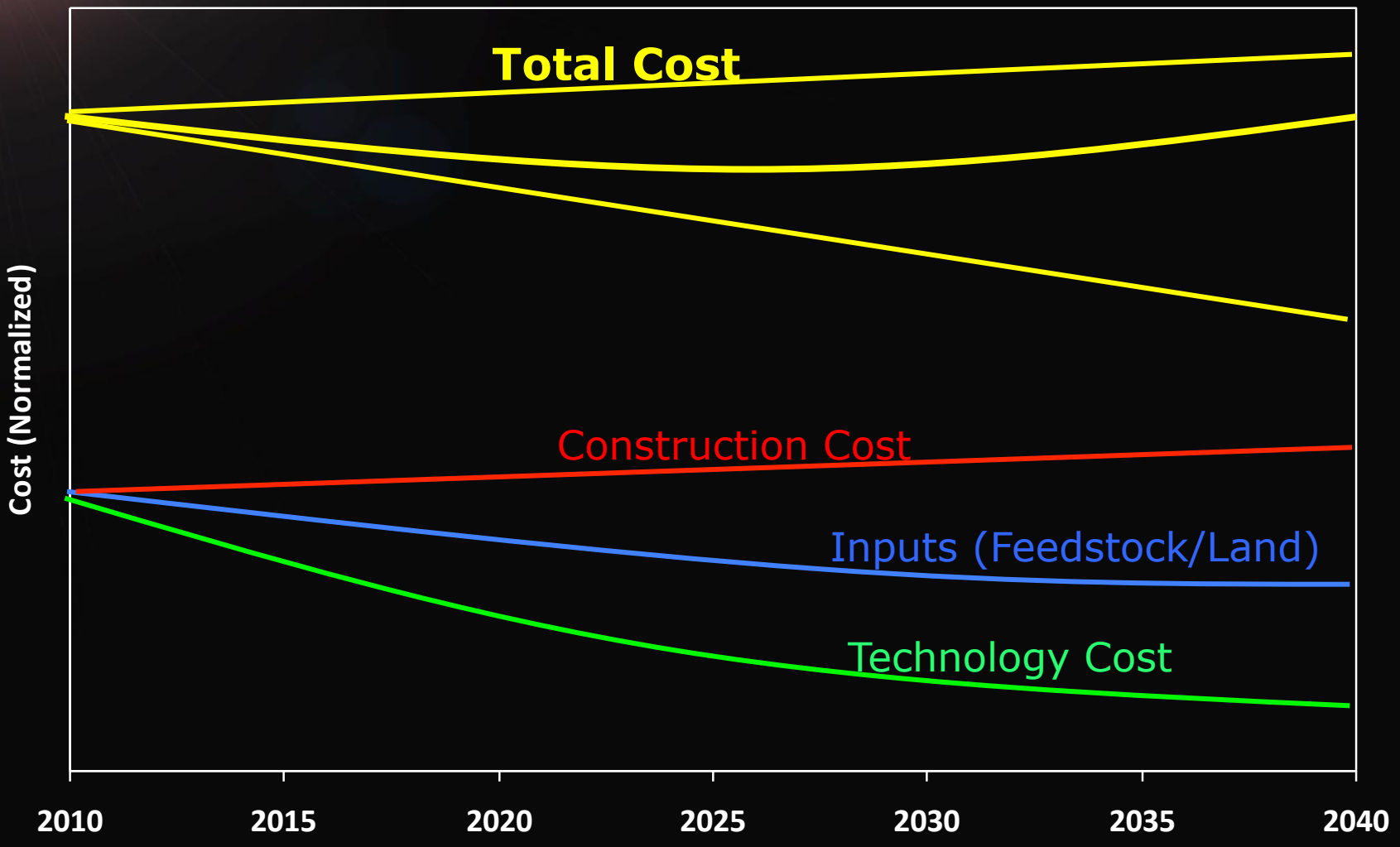
Source: “The Carbon Productivity Challenge”, McKinsey – Original from UC Berkely Energy Resource Group, Navigant Consulting

declining technology cost…

Generations of Solar Photovoltaics…



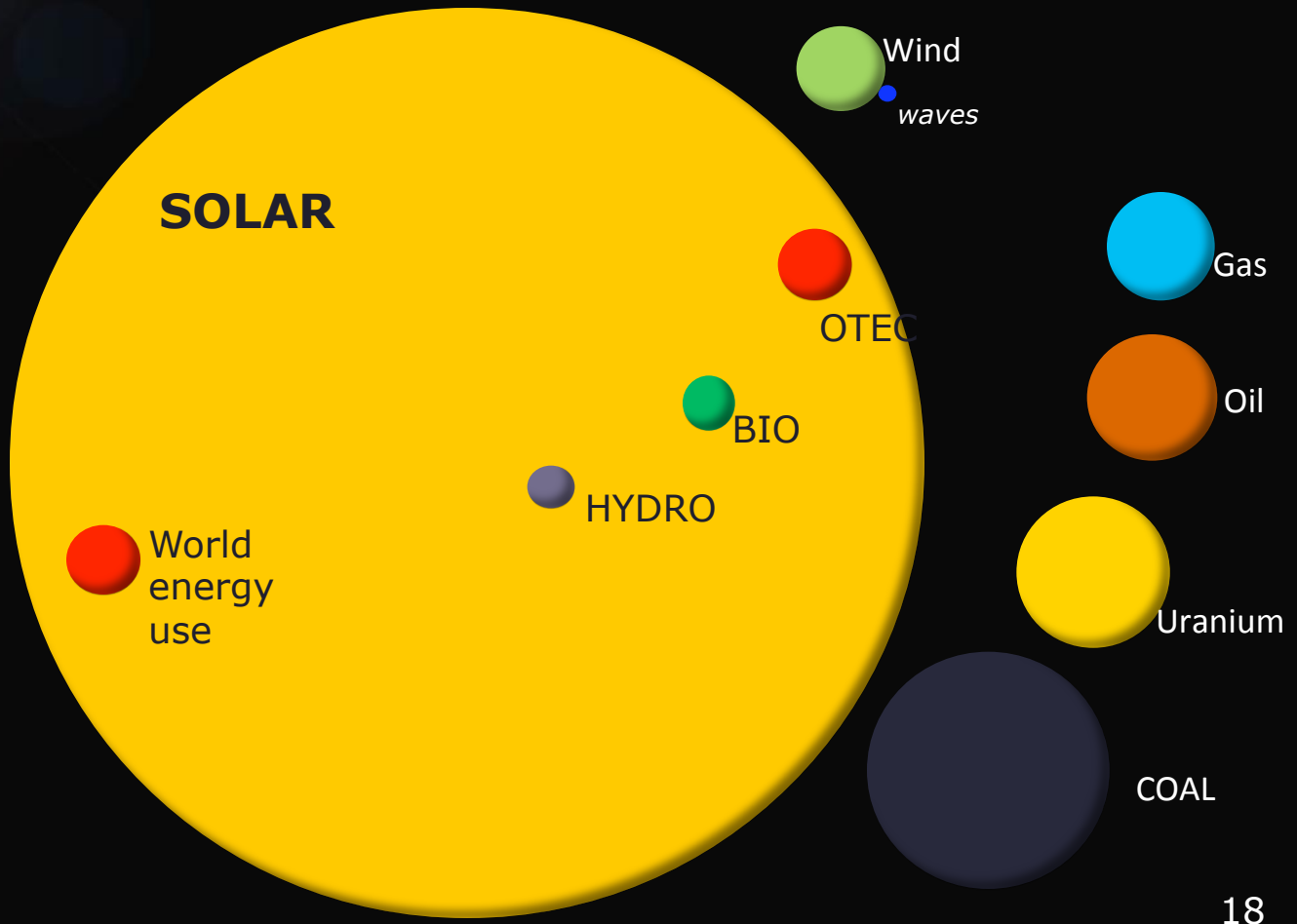
but tech cost decline isn't enough…



Total cost decline is based on relative proportion of cost “types”…

Should we focus on low cost low efficiency cells or high efficiency?

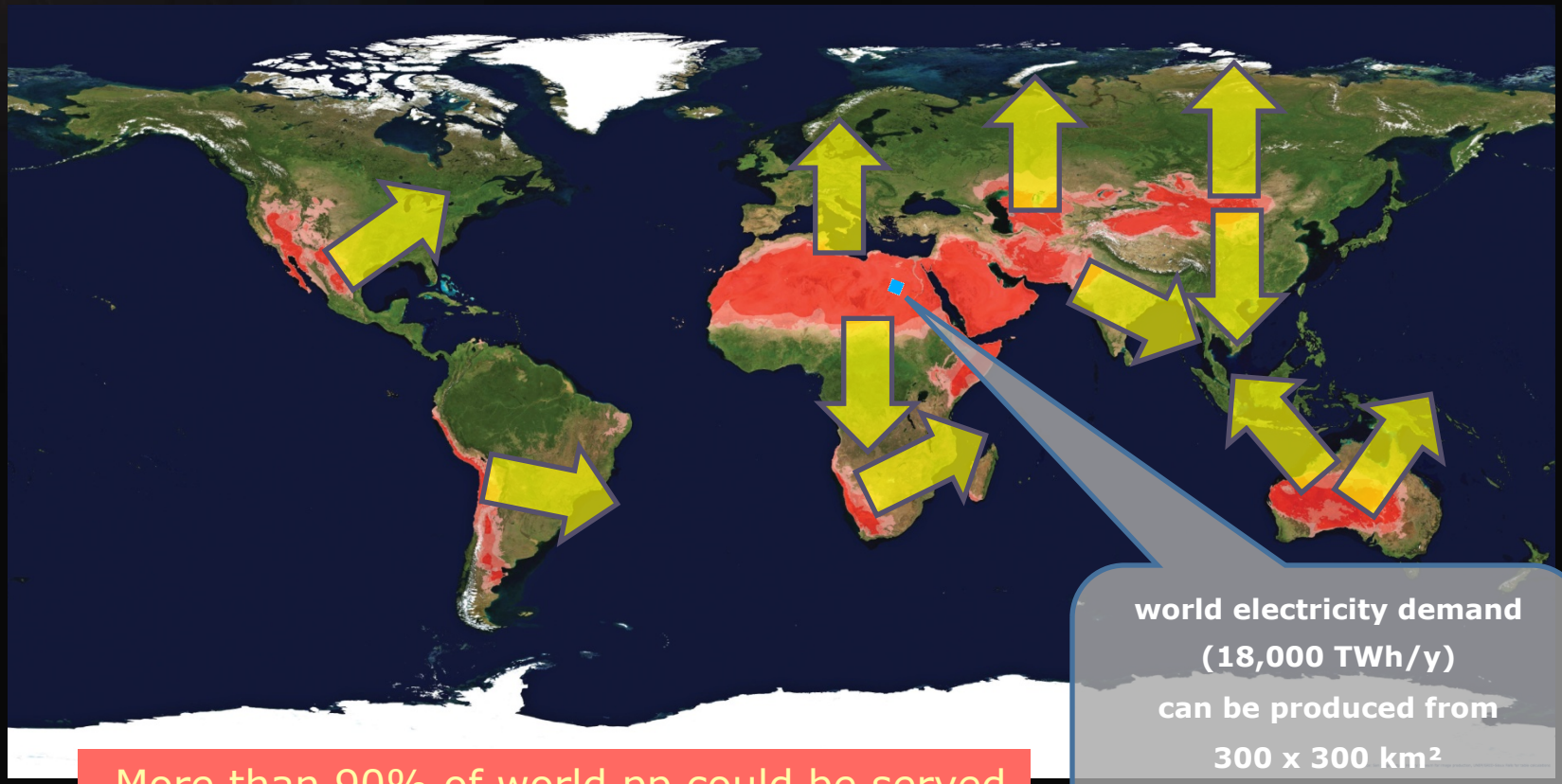
scalability of solar



Source: Gerhard Knies, CSP 2008 Barcelona

land is not a constraint

3000 km



world electricity demand
(18,000 TWh/y)
can be produced from
300 x 300 km²
=0.23% of all deserts
distributed over "10 000" sites

More than 90% of world pp could be served
by clean power from deserts (*DESERTEC.org*) !

Source: Gerhard Knies, CSP 2008 Barcelona

capital formation

- **Short Innovation Cycles (3-5 years)**
  - Not “fusion”; Not “nuclear”; Not CCS
- **Mitigate technical AND/OR market risk quickly and cheaply**
  - (technical) - solar thermal
  - (market) – corn ethanol
- **Investor returns at each stage of technology development**
- **Unsubsidized market competition: 7-10 years**

Private money will flow to ventures that return investment in 3-5 year cycles!

capital formation: pathway for solar thermal

- 2008: Proof of concept mitigating technology risk
  - Costs at $0.16 per KWh
- 2010: Deployment as peaking power (vs. natural gas)
  - Costs at $0.12-$0.16 KWh
  - Less with low cost debt
  - Ongoing tech optimization & storage
- 2013-15: Deployment as base-load (vs. coal)
  - Costs at $0.10-$0.12Kwh including storage
- Adoption risk: PUG power, cost

Note: All costs in 2006 $

…solar

PUG power to drive investment?

- Cost
  - Competitive with fossil fuels
- Dispatchability
  - Power availability must match consumer demand
- Reliability
  - “Utility Grade” capacity factor

Economics, not sentiment, will drive solar adoption

PuG power requirements

	Coal (PC)	Coal IGCC +CCS	Nuclear	Natural Gas	Wind	Solar (PV)	Solar (CSP)	Engineered Geothermal
Scalability	High	CO2 Storage	Med**	High	Low*	Low*	High	High
Reliability	High	Low	High	High	Low*	Low*	High	High
Price Stability	Med	Med	Low-Med	Low	High	High	High	High
Carbon Price Benefits	Low	Low	High	Med	High	High	High	High
Dispatchable Power	Yes	Yes	Yes**	Yes	No	No	Yes	Yes
Adoption Ease	High	Low	High**	High	Low	Med	High	High
Technology Risk	Low	High	Med	Low	High Low	High Low	Med	High

*Wind and Solar PV are severely disadvantaged due to the lack of storage – power is available when generated, not when needed, stopping them from serving as base-load power generators

** Nuclear energy is "always on", generating electricity even when it is not needed (and when prices are negative, such as the middle of night). High decommissioning costs and a lack of effective waste-disposal are both significant factors in limiting its scalability

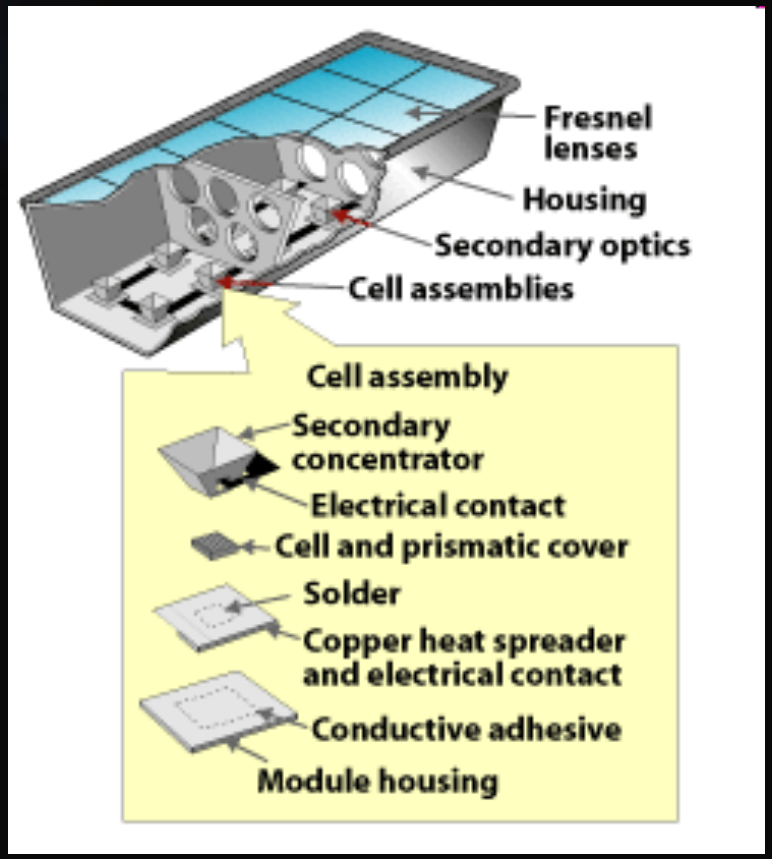
CSP and EGS meet Utility Needs!

solar

- CPV
- CSP
- Storage
- Next Steps

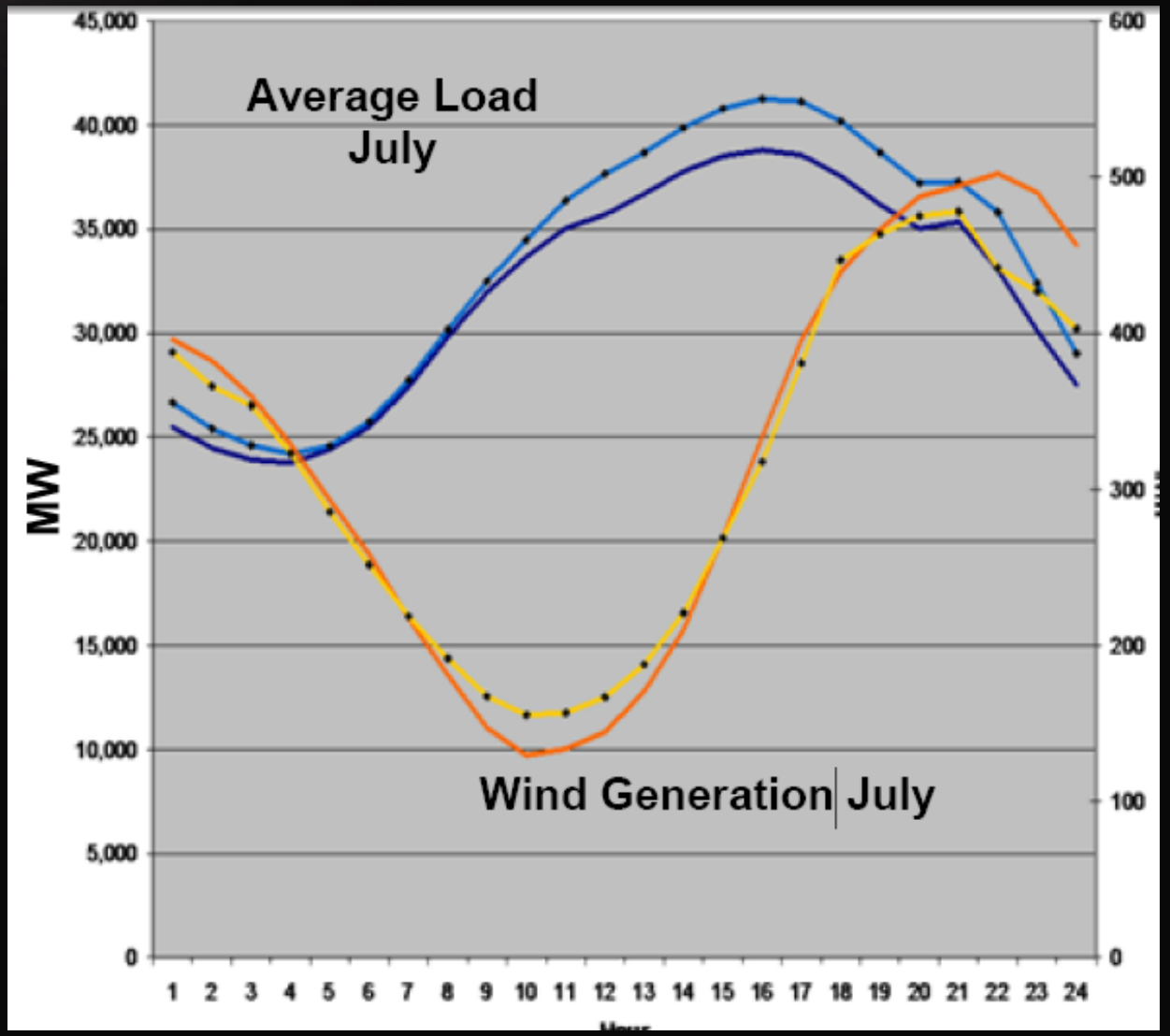
CPV

a concentrated PV cell



Source: NREL

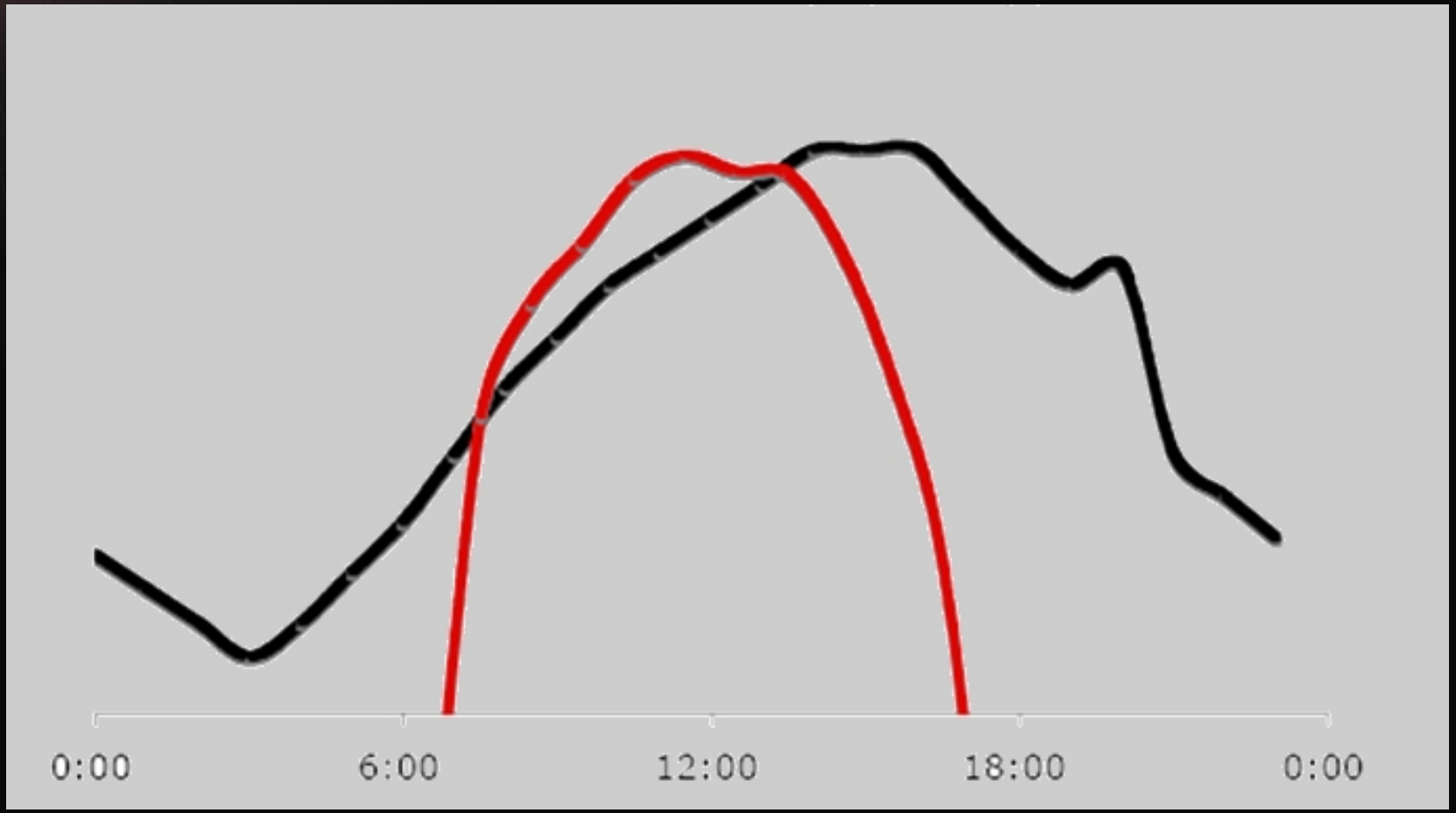
wind vs. grid load (July in CA)



Source: NREL, CAISO data

Wind needs storage to meet utility grade!

daily solar vs. grid load (July in CA)



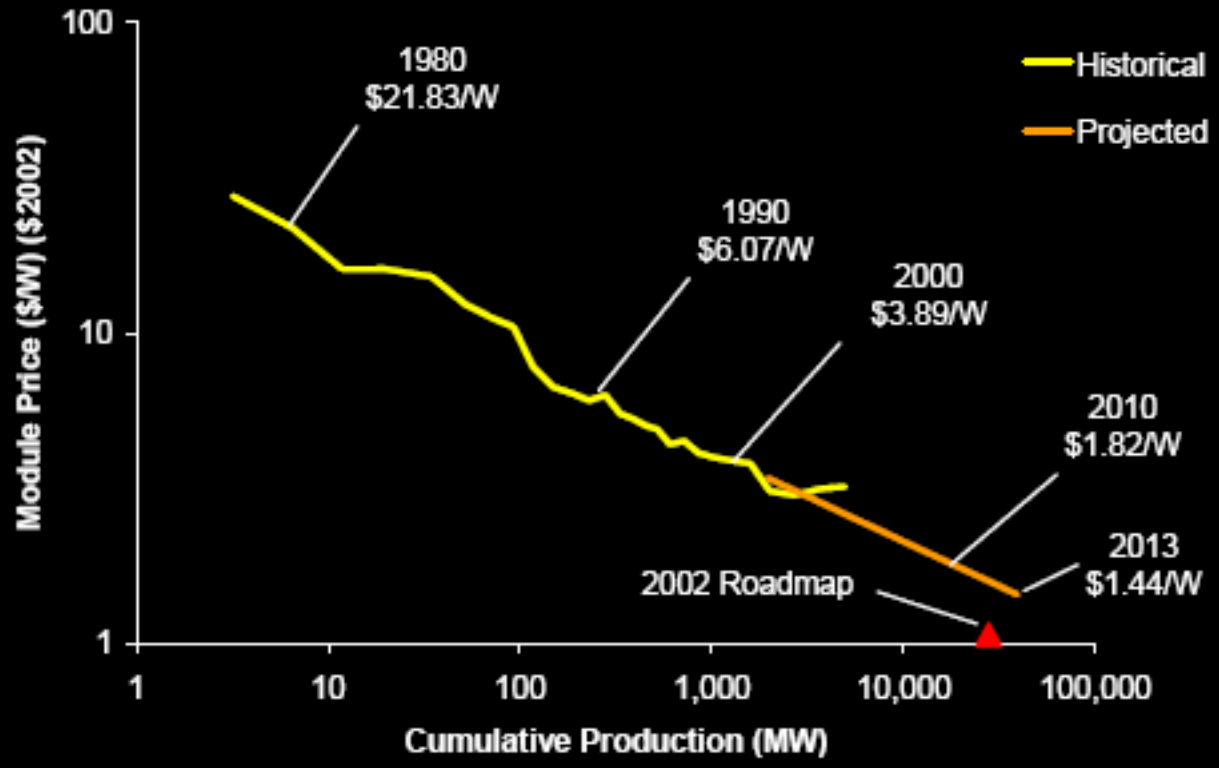
Source: NREL, CAISO data

Solar has greater correlation with load than wind!

… but it isn’t enough!

SUNPOWER

Solar Panel Learning Curve Predicts Retail Rate Parity < Decade



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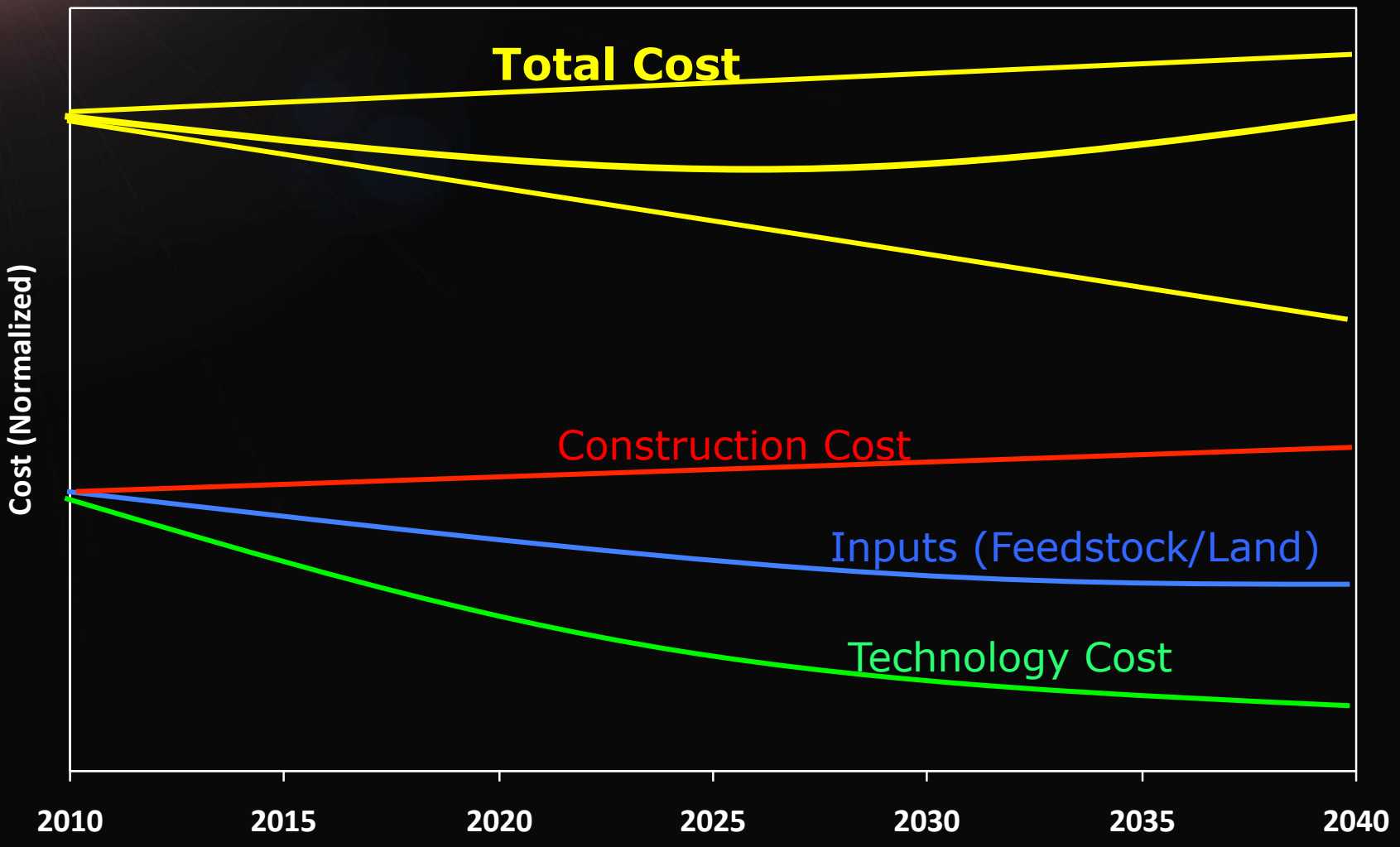
Source: Sunpower

but tech cost decline isn't enough…



Total cost decline is based on relative proportion of cost “types”…

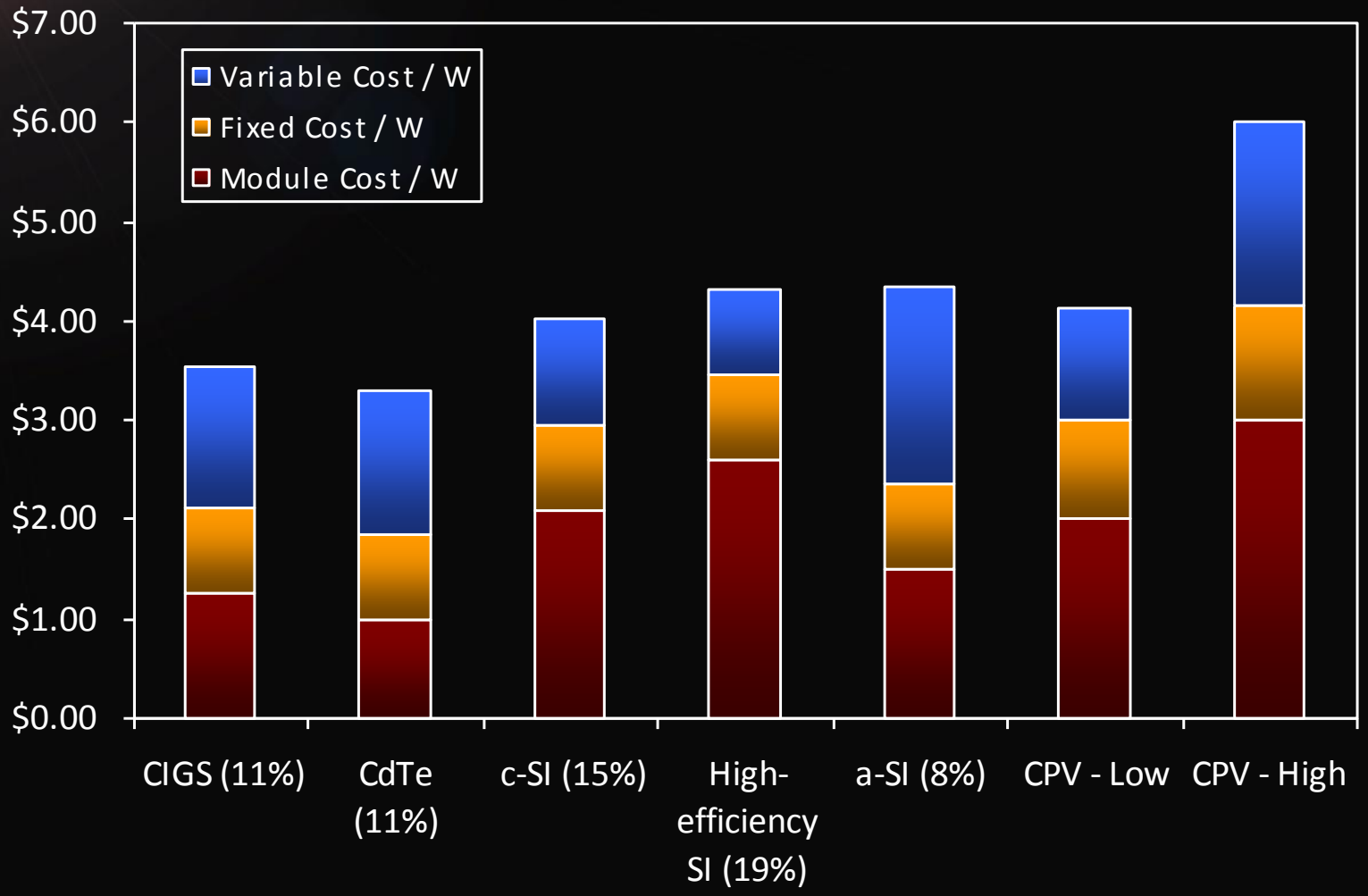
Should we focus on low cost low efficiency cells or high efficiency?

CPV breakdown

System	Concentrator Technology	Power Conversion
Dish CPV	Parabolic Dish	Multi-Junction or Silicon PV
Lens CPV	Lens of Fresnel Lens	Multi-Junction PV
LCPV	Low-Concentration Reflector	Silicon PV
Non-Tracking PV	Non-Tracking Concentrator	Multi-Junction or Silicon PV

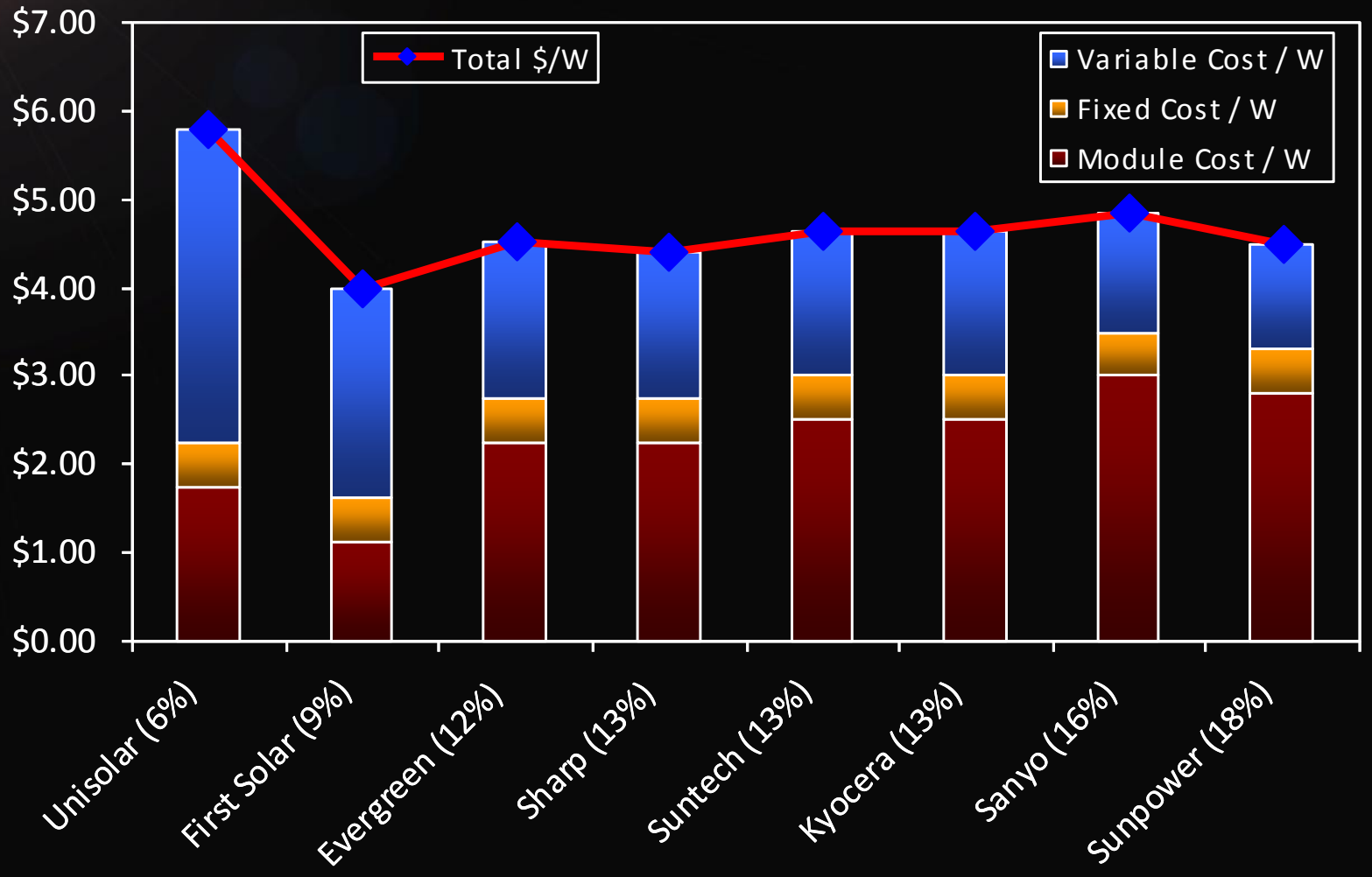
Source: Prometheus Institute, Greentech Media

breaking down PV costs



Source: Stion, ORNL solar summit

is efficiency the goal?



Source: Stion

Efficiency = lowest cost?
Low cost cells = lowest cost?

CPV questions?

- Is any configuration cheap enough?
- What is the trajectory of costs?
- What concentration? What cell type?
- Black Swan's: Trackerless concentration? Storage?

left field innovation

- New locations: rooftops, parking lots

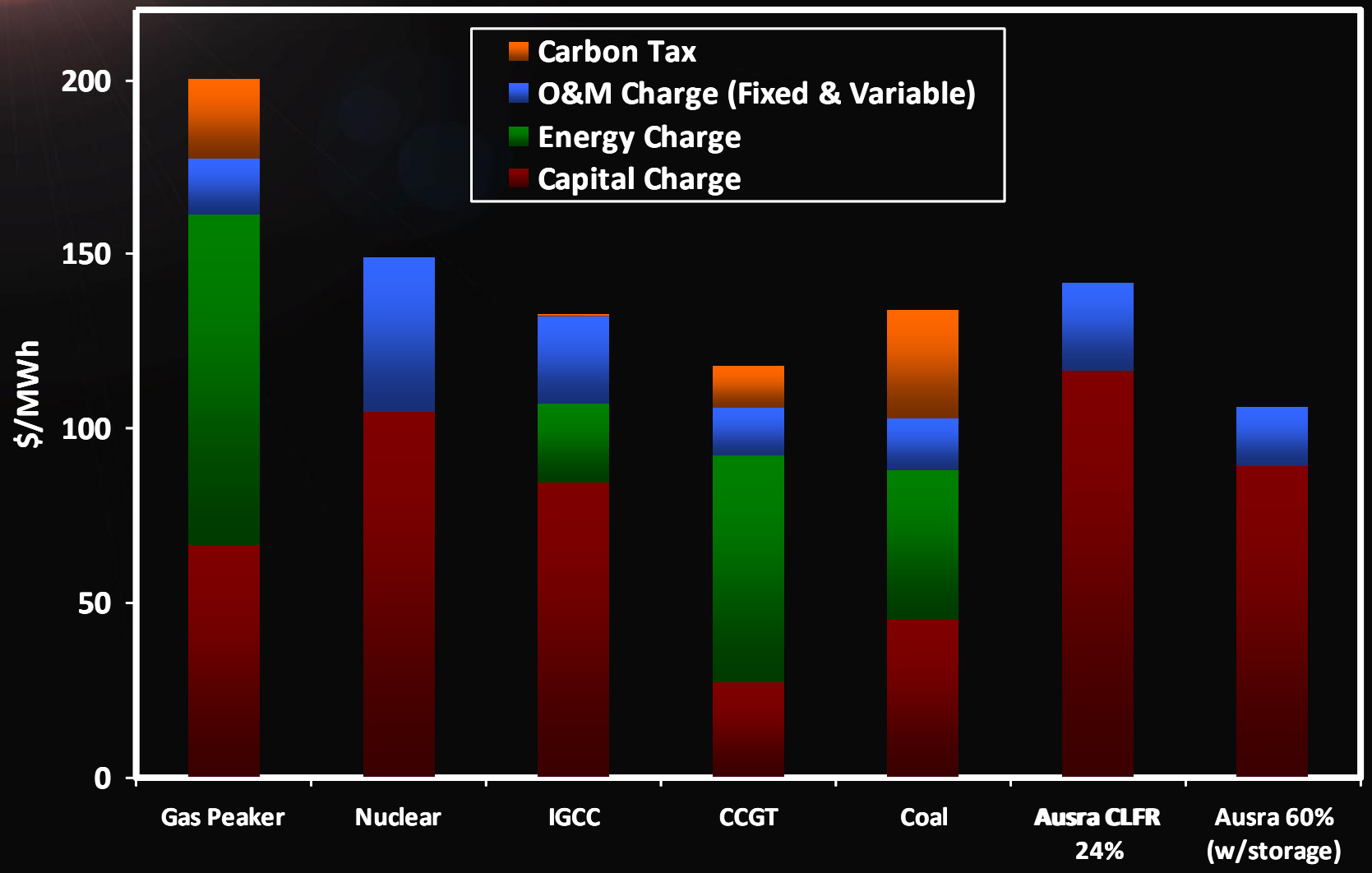
- CPV with hydrogen – regenerative fuel cells?

CSP

how soon Is solar competitive?

- Residential:
  - $.20+/kWh average
  - Maximum scale limited to 10%
  - Subsidy dependent
- Centralized:
  - Gas Peaking $.16/kWh
  - Gas CC $.10-0.12/kWh
  - Coal $.08+ /kWh
  - Cost sensitive to carbon price

price of power - 2011 and 2013



Source: Ausra. All prices are estimated as of April 2008, in 2008$; Carbon tax of $30 is assumed. Ausra CLFR 24% price is as of 2011, and 60% w/storage is in 2013

Solar Peaking Pricing

Solar Baseload Pricing

solar thermal power systems

Dish

Tower

Trough

Linear Fresnel

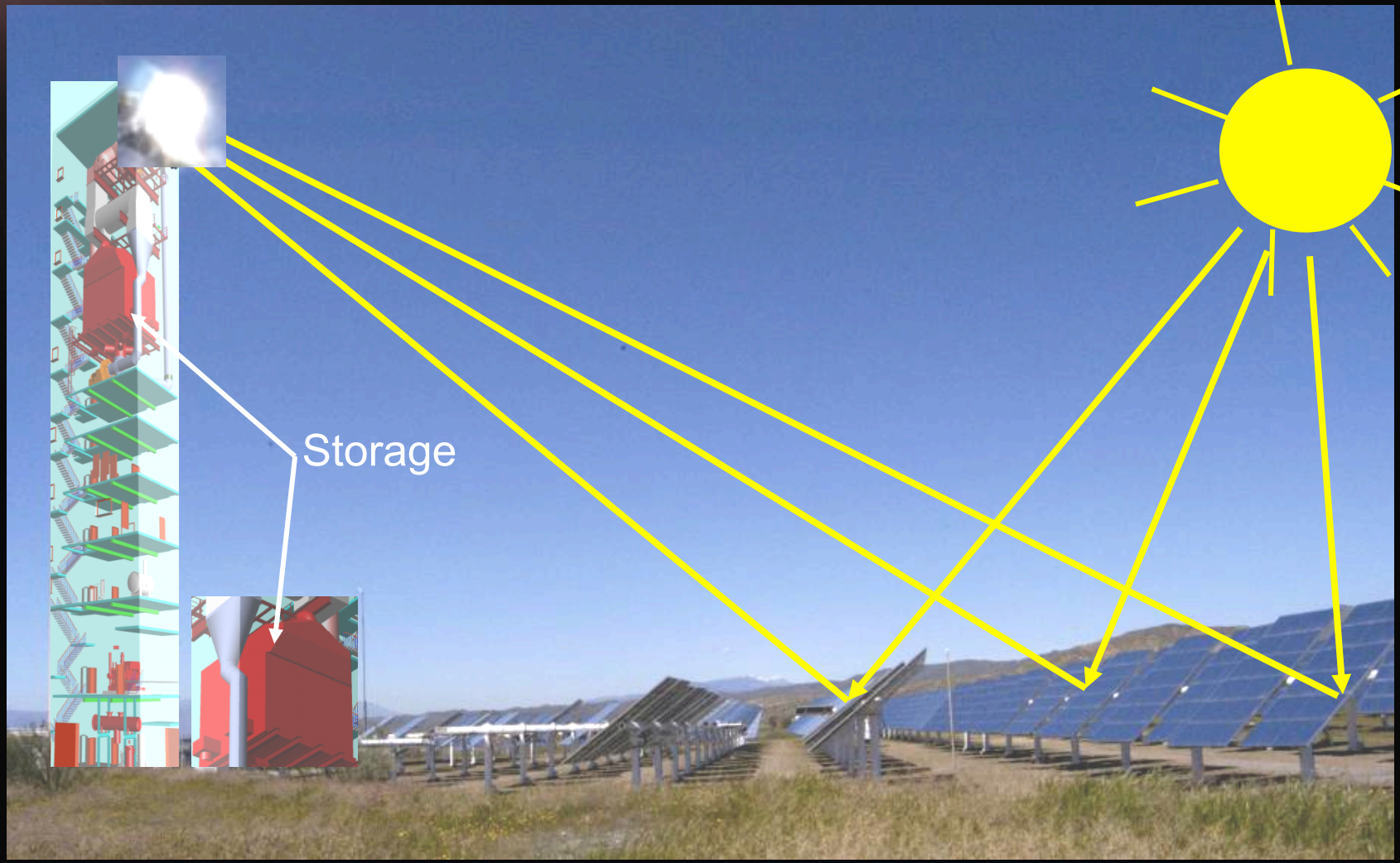
dish-engine

www.stirlingenergy.com

power towers

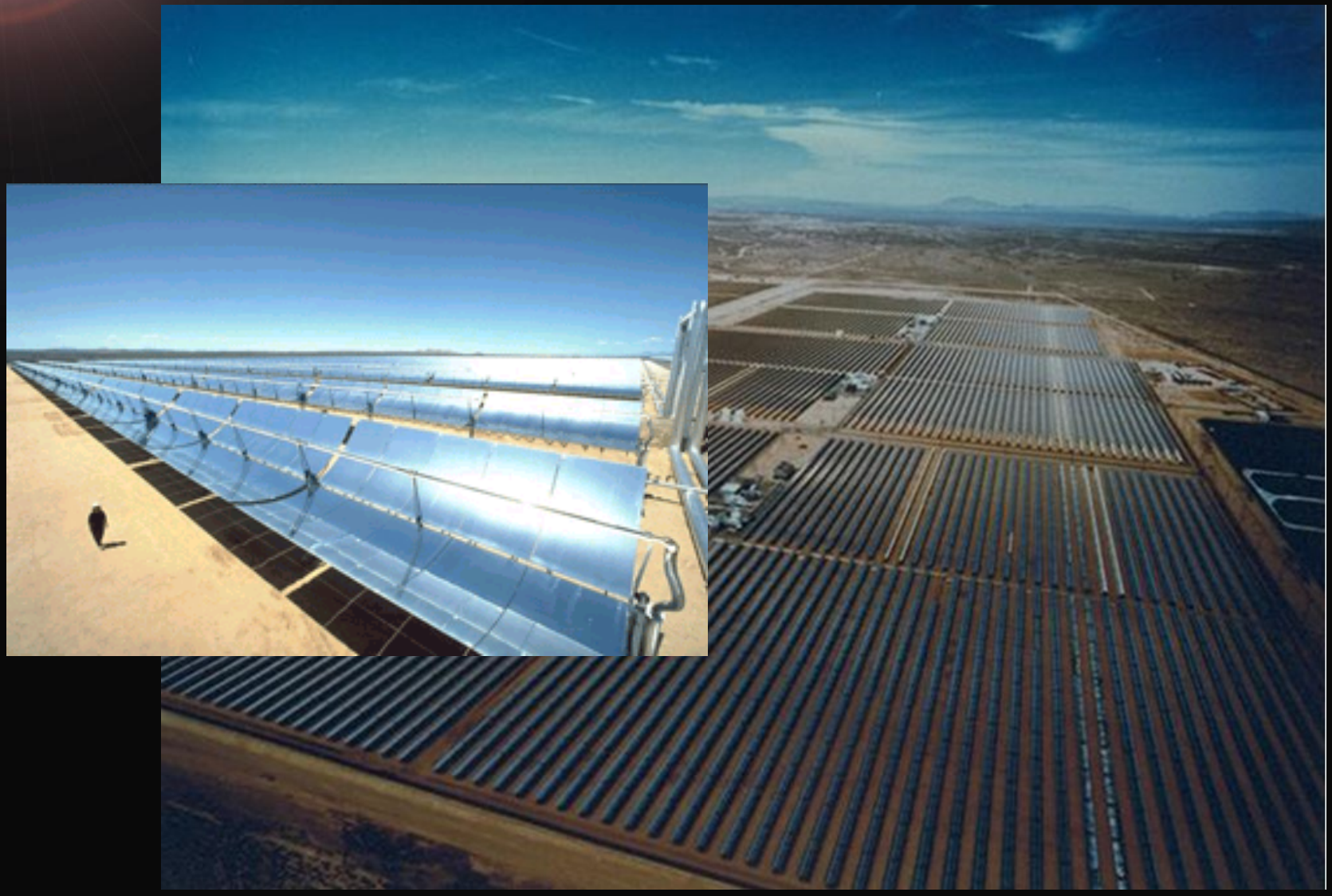
Solar Two, 10MW, Barstow, CA

concept of tower technology



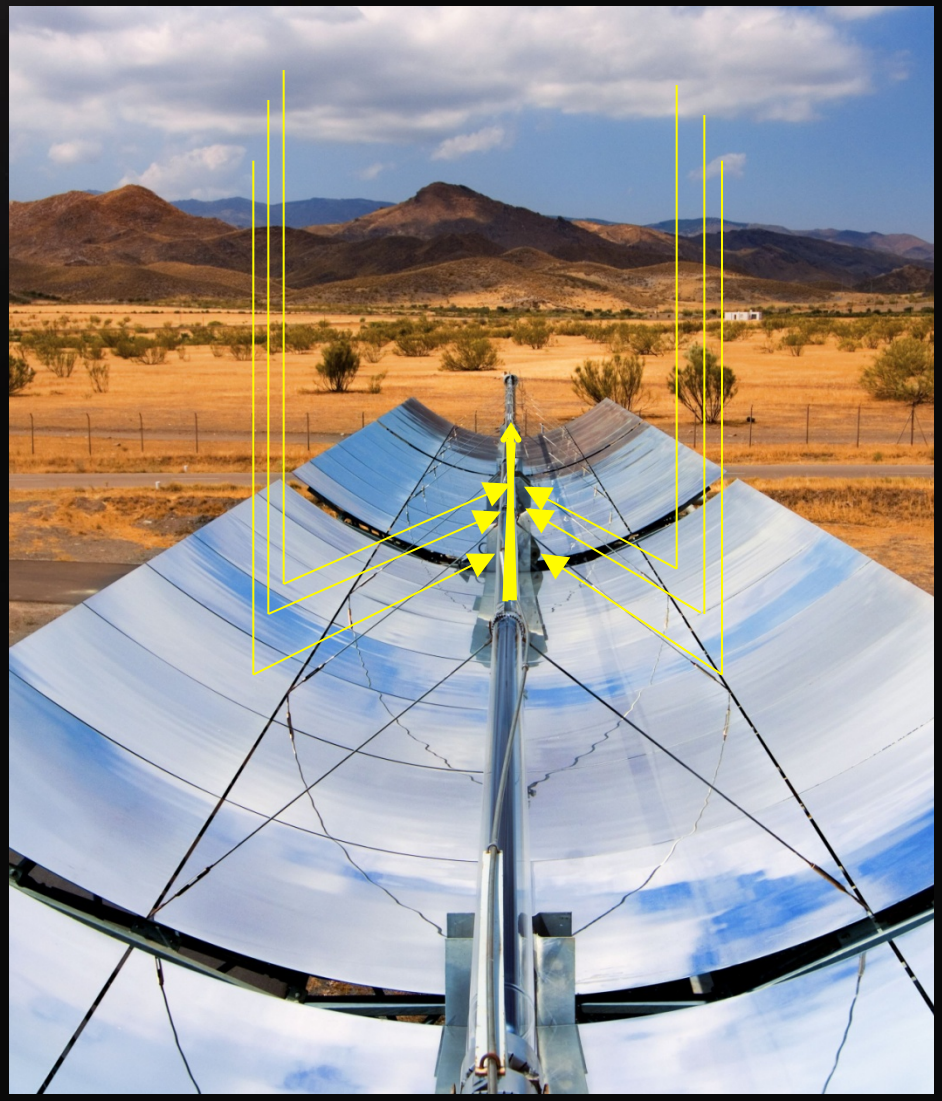
Source: Bernhard Hoffschmidt, Drectior – Solar Institute Julich

parabolic troughs



Solar Electric Generating Stations, 354MW, Boron and Harper Lake, CA

parabolic troughs - how they work



Source: Robert Pitz-Paal, DLR

compact linear fresnel reflector

questions to ponder

- Efficiency or cost/kw?

Power Tower or CLFR

- Storage & Dispatchability

Peak vs Base Load

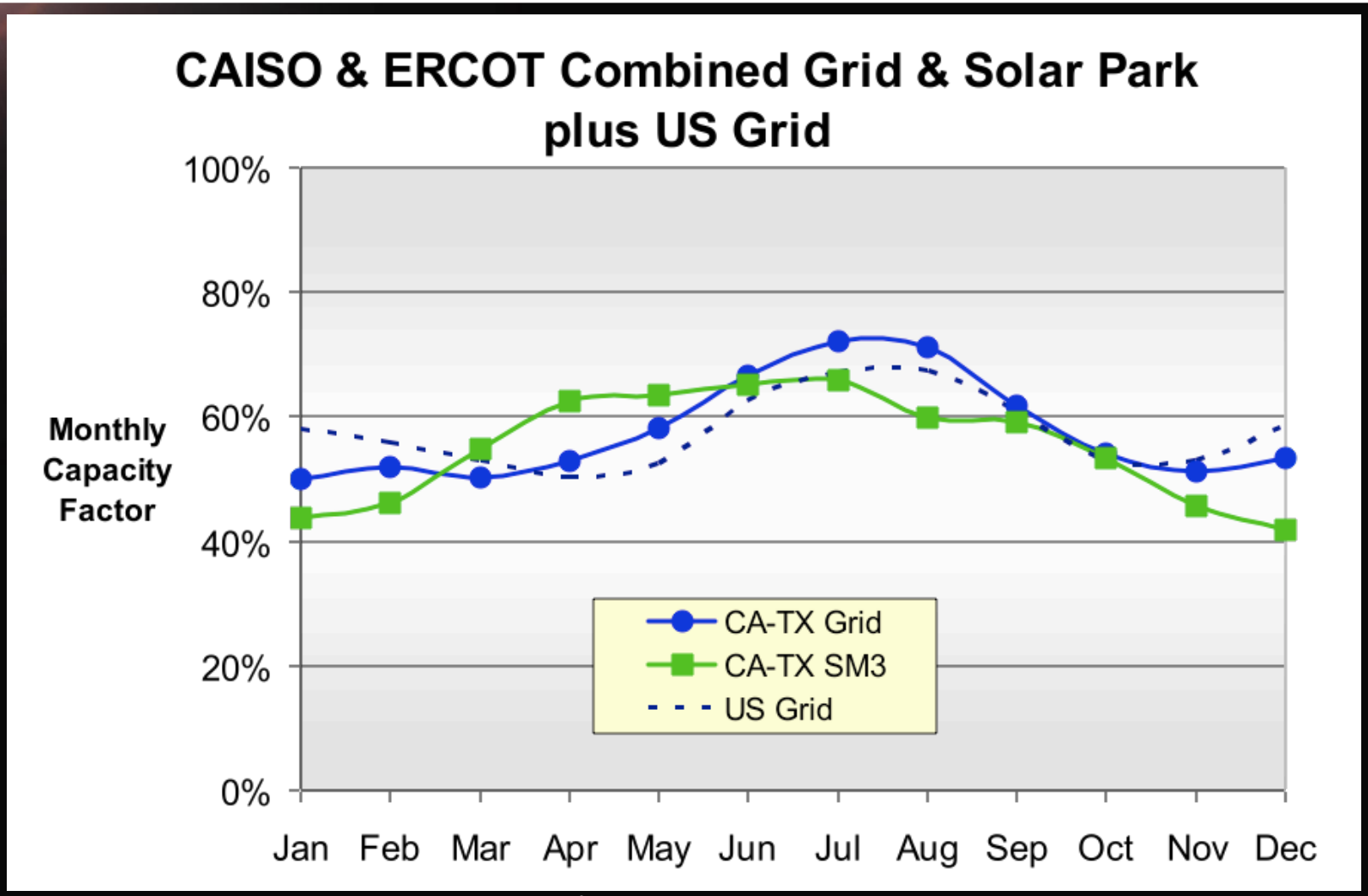
- Capacity Factor

scalability: CSP

- CSP in the Southwest >> all US power
- Low cost storage = base load power
- CSP: 16 months, not 16 years (Nuclear)

Source: WGA Study; Mark Mehos and Dave Kearney, KV

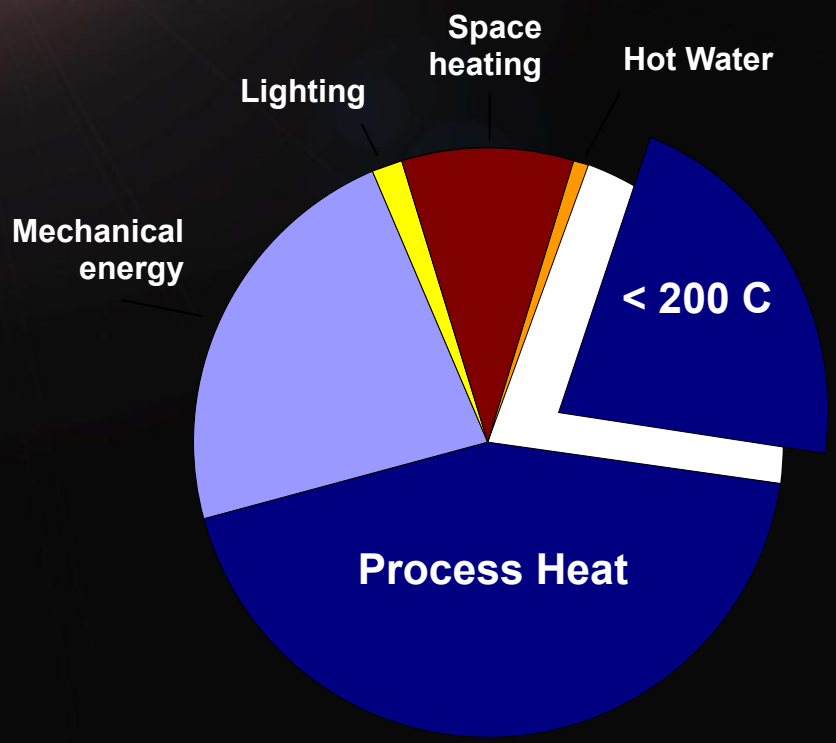
solar thermal can supply over 95% of US grid



Source: Solar Thermal Electricity as the Primary Replacement for Coal and Oil in U.S Generation and Transportation, David Mills and Robert Morgan

Assumptions:
-16 hrs storage, using national monthly average (not hourly) load data
- plant fleet assumption = current US levels of 1067 GW installed and 789GW non-coincident peak load
- Based on current technology, (CLFR with 3X (Sun concentration) this would require land area of 153 x 153 KM

solar: the process heat applications?



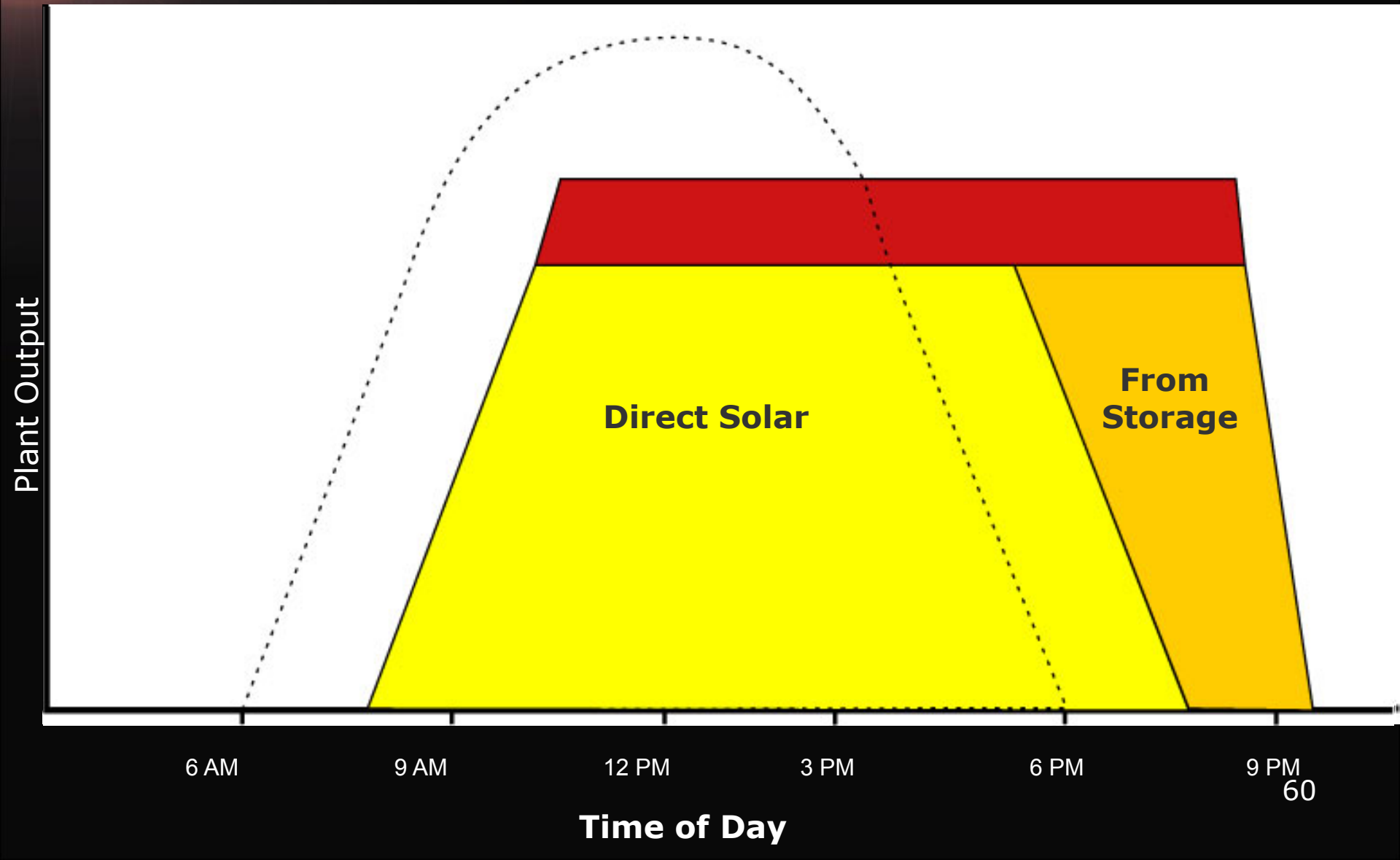
- 2/3 of industrial end energy = process heat
- 1/3 of process heat < 200 C
- Huge potential for solar energy!

Food Industry
Textile Industry
Chemical Industry
Cooling / Air Conditioning

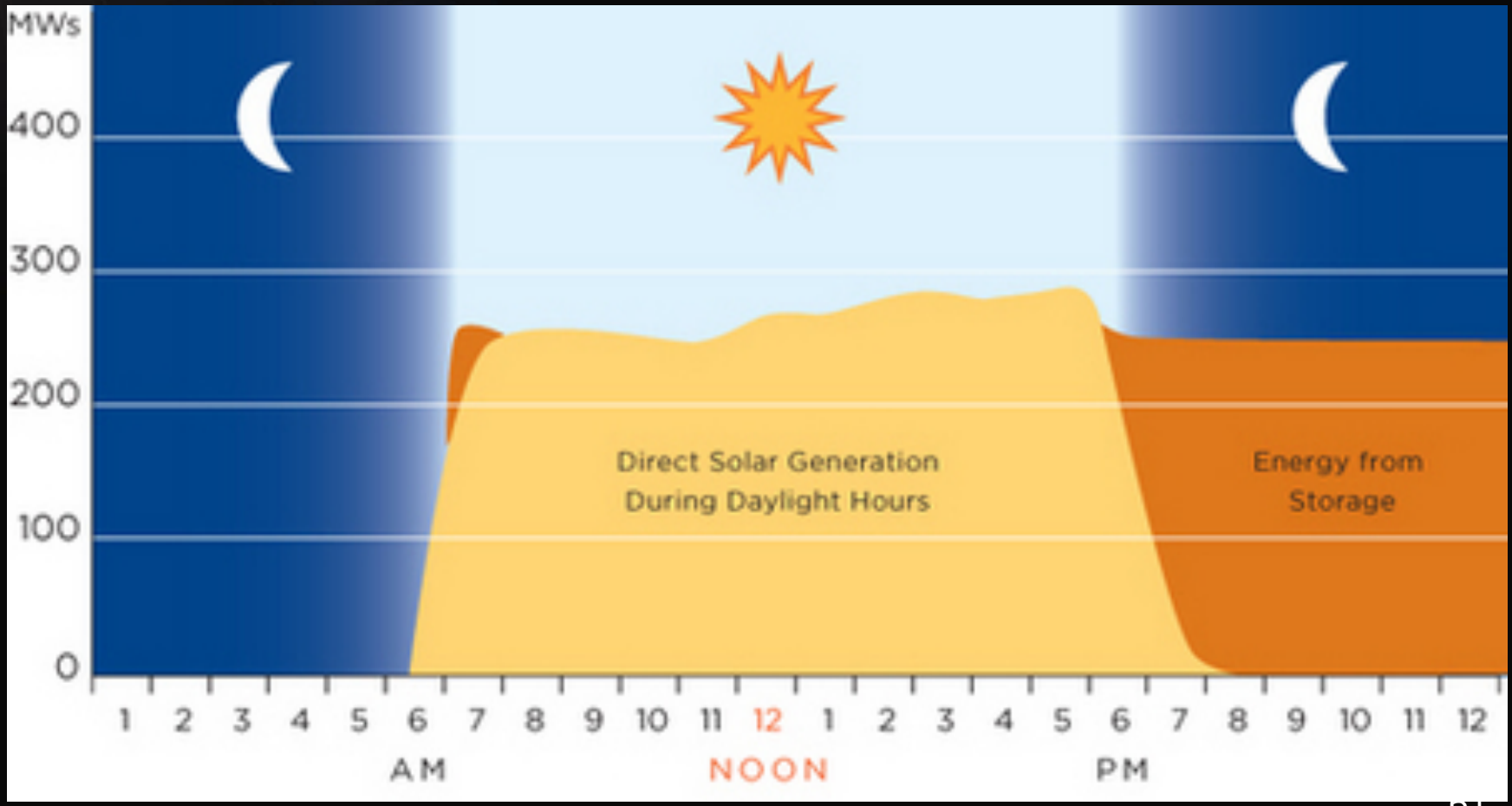
Source: Dr. Andreas Häberle PSE AG, Freiburg / Germany

Storage

Storage For Time-shifting



solar thermal: day / night power



Source: John O' Donnell

Optionality: thermal storage is cheap

Electricity

- Flywheel ≈ $4000/kWh
- VRB batt ≈ $350-600/kWh

increased cost of power

Heat/Air/Hydro

- Molten Salt ≈ $45/kWh
- Concrete ≈ $25-45KWh

lower cost of power

- CAES, Pumped Hydro

Source: NREL for heat storage (2007), Dr. Doerte Laing, DLR (2008), VRB battery costs from company and Appalachian Power, CAISO estimate for Flywheel costs (Beacon Power)

Optionality: thermal energy storage

- **Commercial Available Today**
  - Steam Accumulator
  - molten salt storage based on nitrate salts

- **In Testing**
  - Solid medium sensible heat storage - concrete storage
  - Latent heat - PCM storage
  - Combined storage system (concrete/PCM) for water/ steam fluid
  - Improved molten salt storage concepts
  - Solid media storage for Solar Tower with Air Receiver

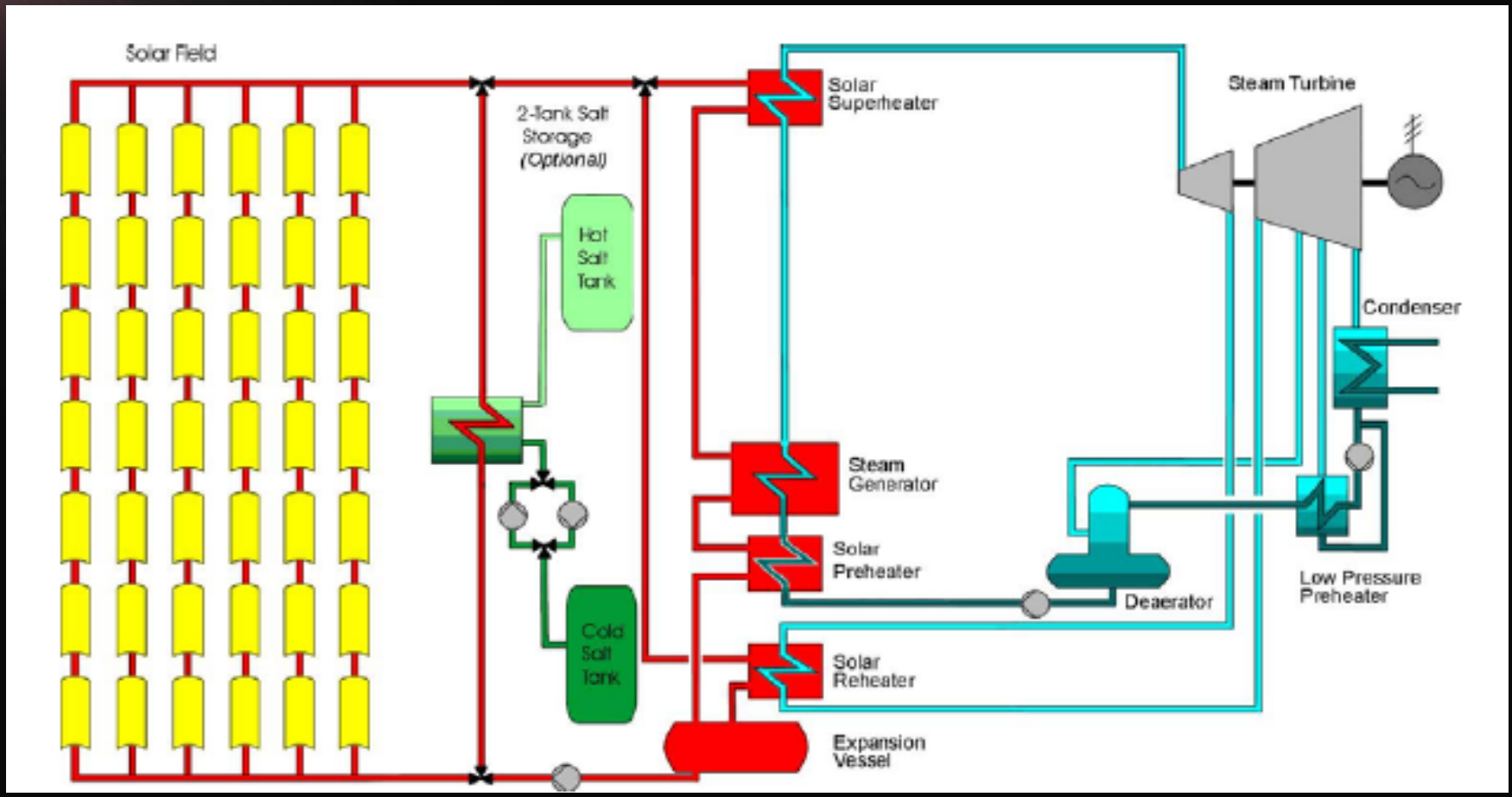
Source: Doerte Laing , German Aerospace center

Optionality: steam accumulators PS10

Source: Doerte Laing , German Aerospace center

Optionality: molten salt storage

Andasol 1



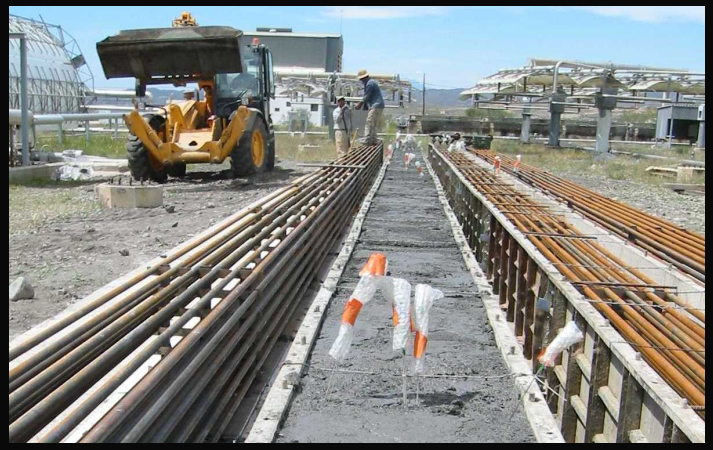
Syn. Oil — $NaNO_3$-KNO_3 — H_2O

Collector field — Molten salt storage — Conventional steam turbine

Source: Doerte Laing , German Aerospace center

Optionality: solid media concrete storage

- Dual medium indirect storage + regenerative heat transfer
- Modular and scalable design from 500 kWh to 1000 MWh
- Cost target < 20 € / kWh TES capacity

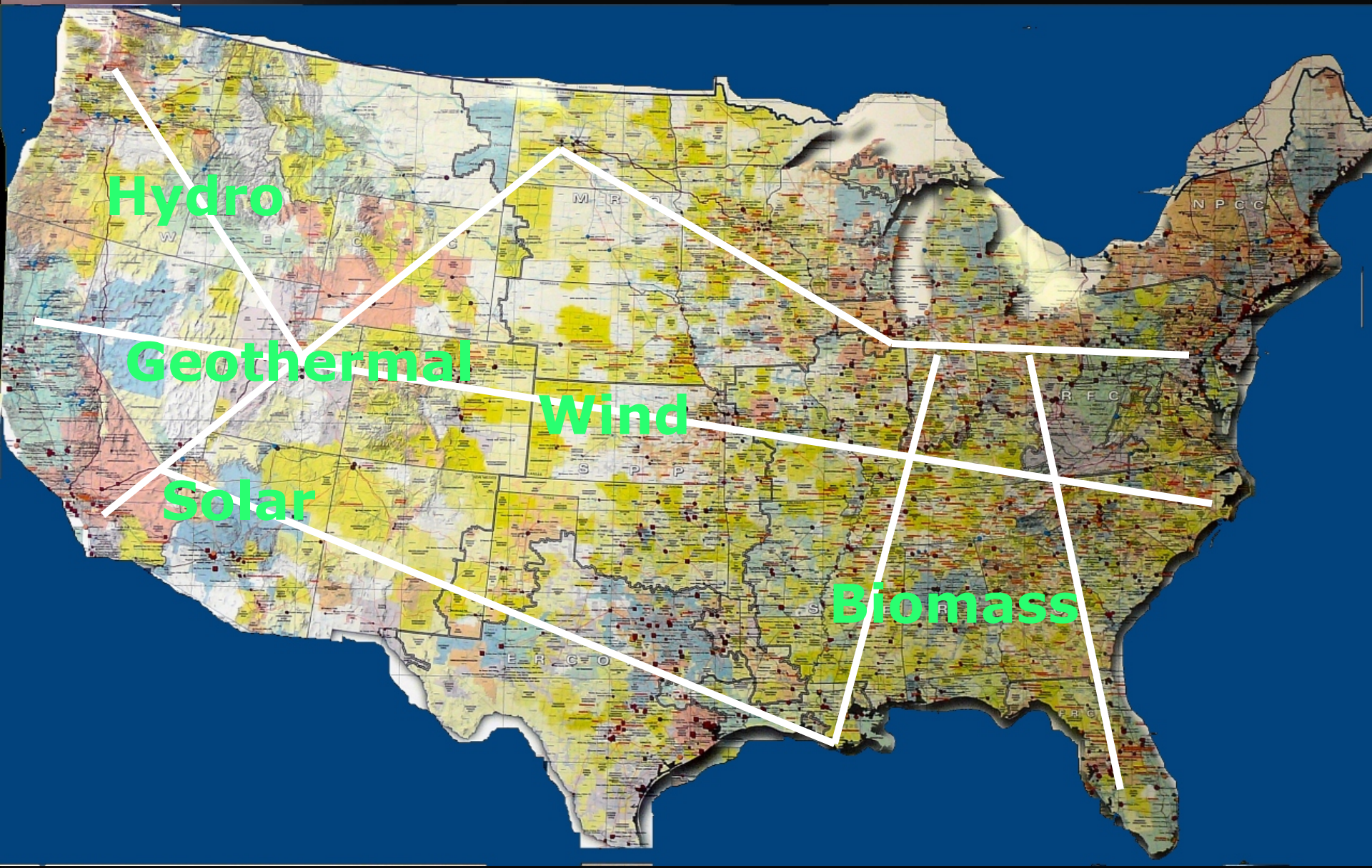


Next Steps

encouraging *the right* innovation: power generation

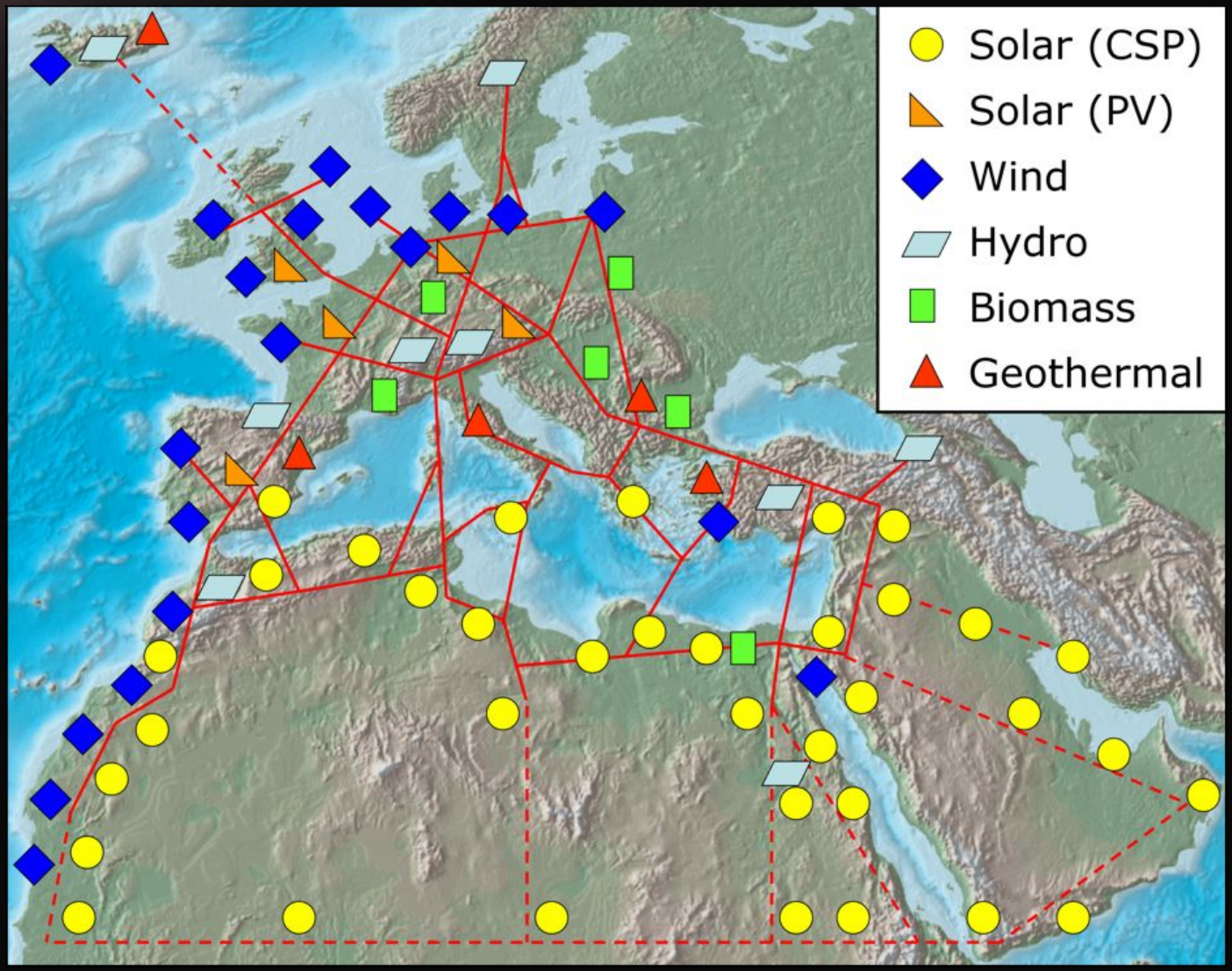
- High-Voltage distribution (DC) grid
- RPS vs. feed-in tariffs
- Reduce cost of capital
- PUG power; Chindia price; scale

encouraging *the right* innovation: HVDC



DESERTEC concept for EU-MENA

10,000 GW from solar!



Gerhard Knies, Taipei e-parl. + WFC 2008-03-1/2

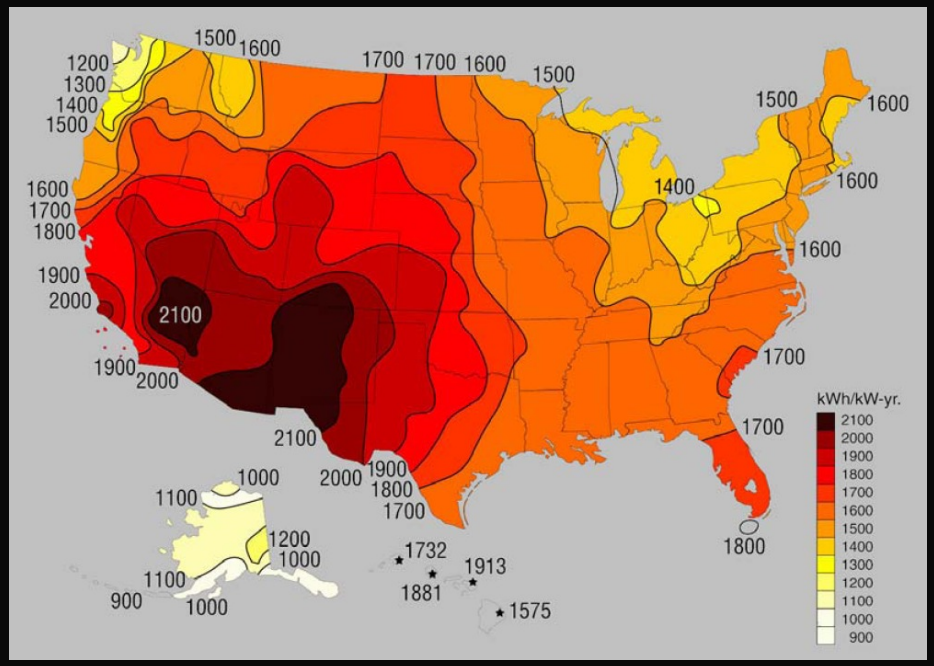
un-sensible things

- Solar in Germany
- San Francisco rooftops vs. Mojave
- Feed-in Tariff vs. RPS

USA… looking good

Germany: 57% world PV

US: 7% world PV



Source: Creating a U.S. Market for Solar Energy, by Rhone Resch, President of the Solar Energy Industries Association.

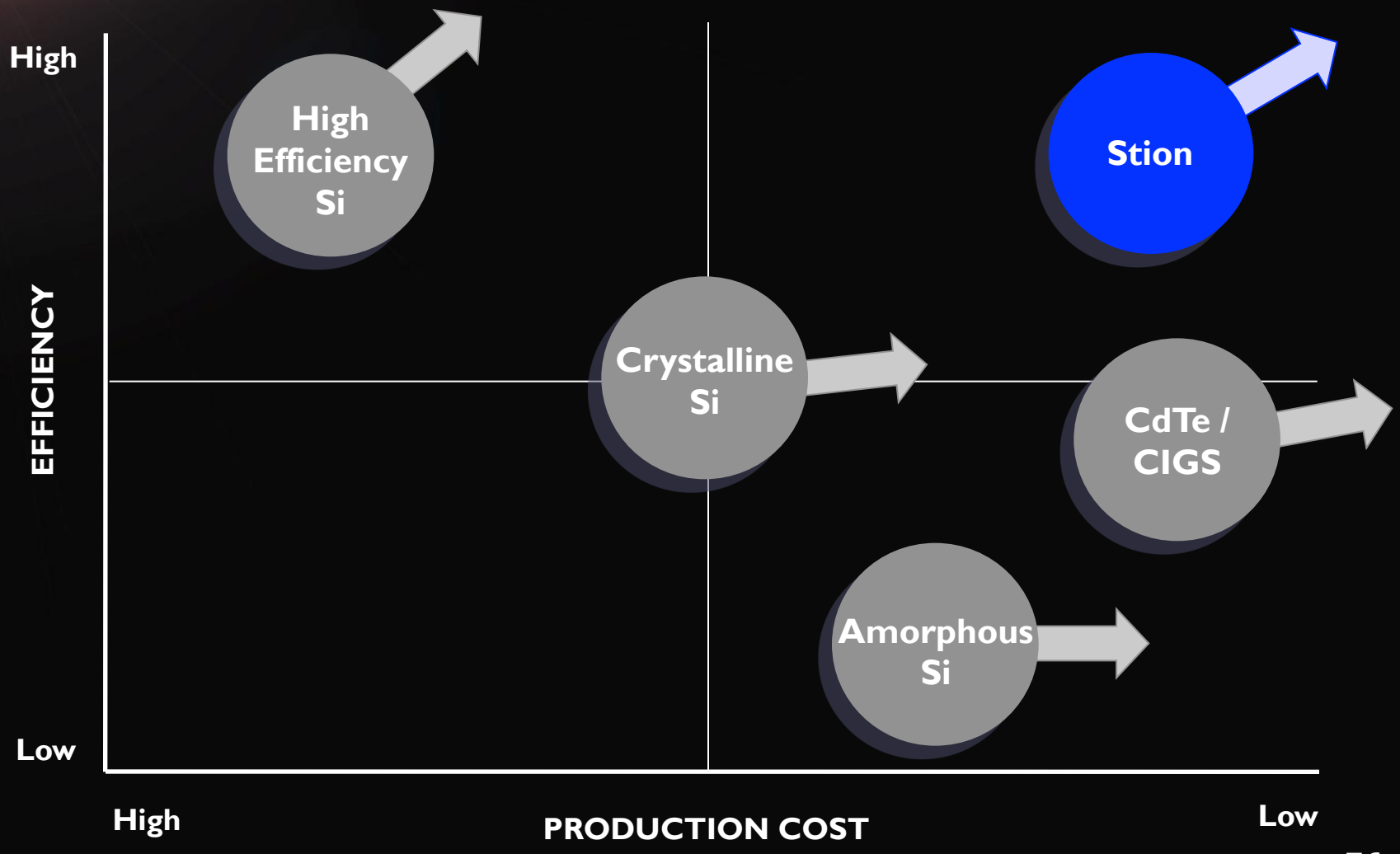
SF or Mojave Desert?

Or

khosla ventures portfolio

Ausra CLFR

Stion: different position in PV



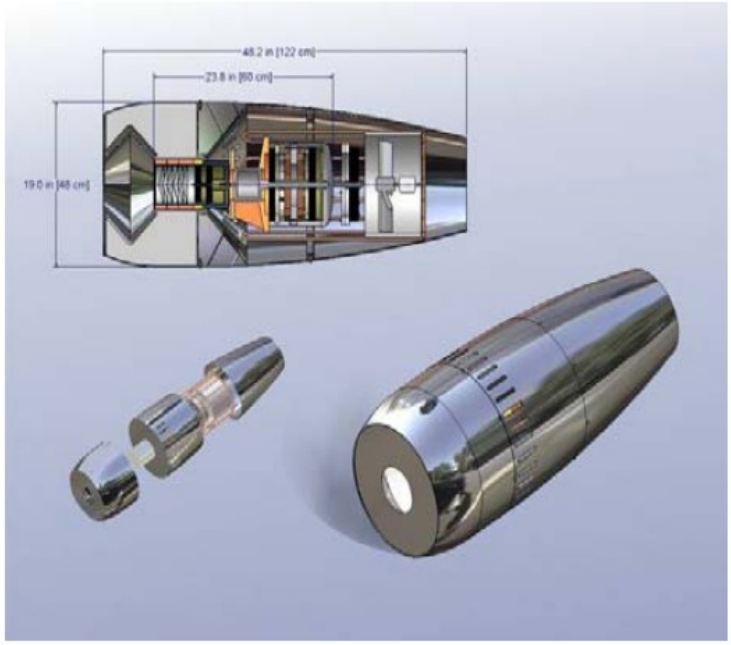
PVT Solar

- generation efficiency is 2-3 times greater than PV alone

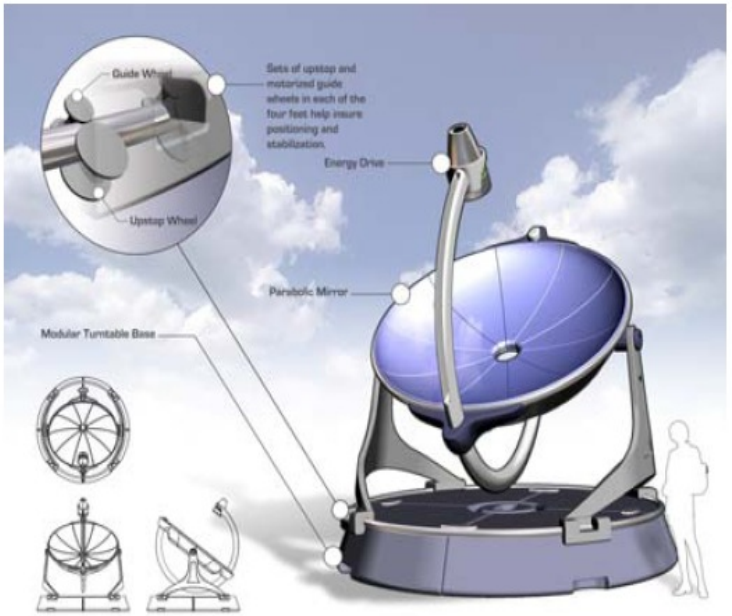
Stirling Engine Technology

- Concentrated solar power systems using proprietary stirling-engines

Infinia's Solar Stirling Engine

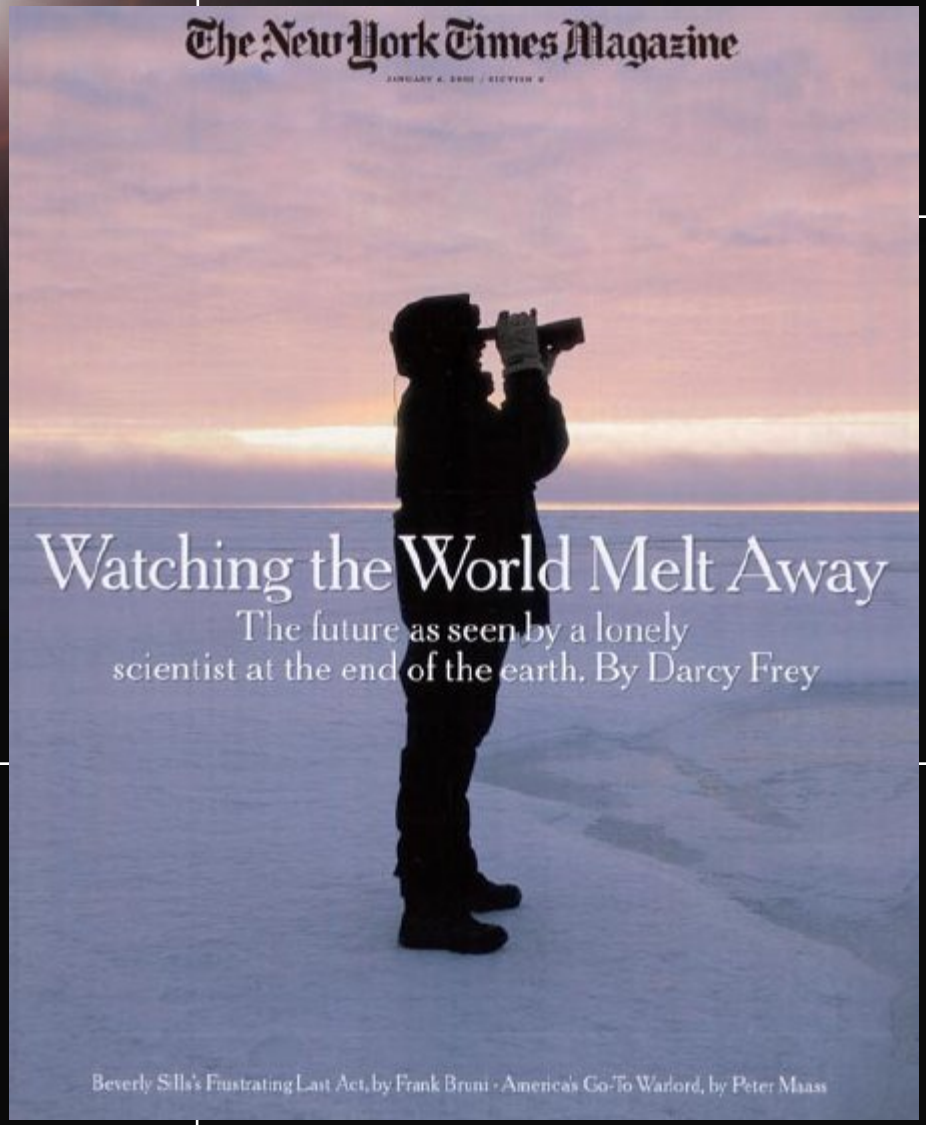


Infinia's Solar Concentrator and Engine System



Plans, resumes, thoughts?

vk@khoslaventures.com
khoslaventures.com / resources.html



...or get to work

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