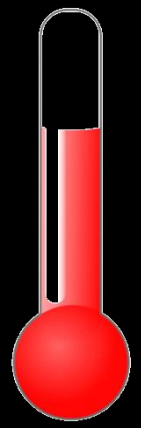
Ultra-High Penetration PV

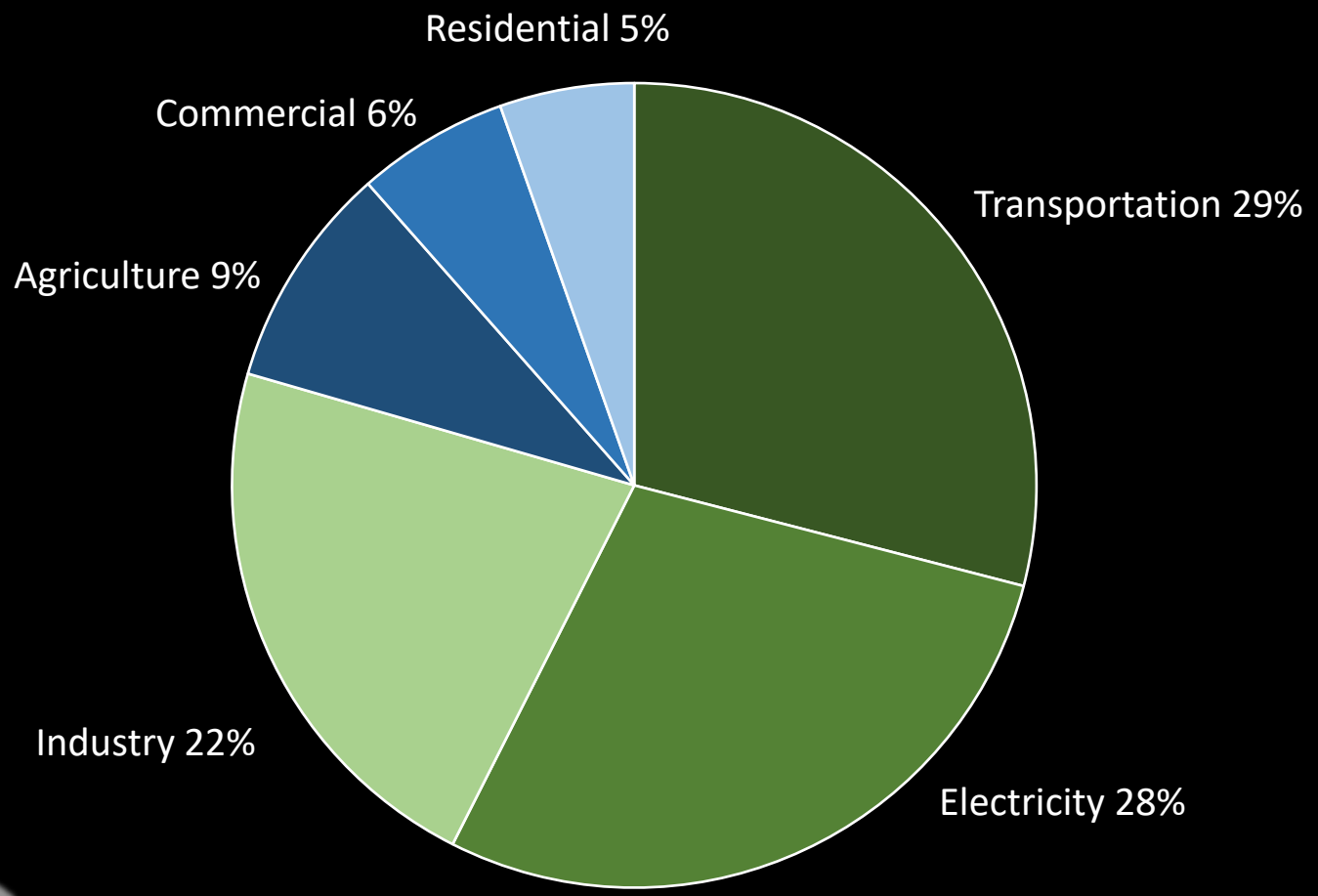
Richard Perez, ASRC

Marc Perez, Clean Power Research
Karl Rabago, Pace University
Morgan Putnam, RESurety
Marco Pierro, University of Rome
Cristina Cornaro, University of Rome
Matteo Giacomo Prina, EURAC
David Moser, EURAC

THE PROBLEM

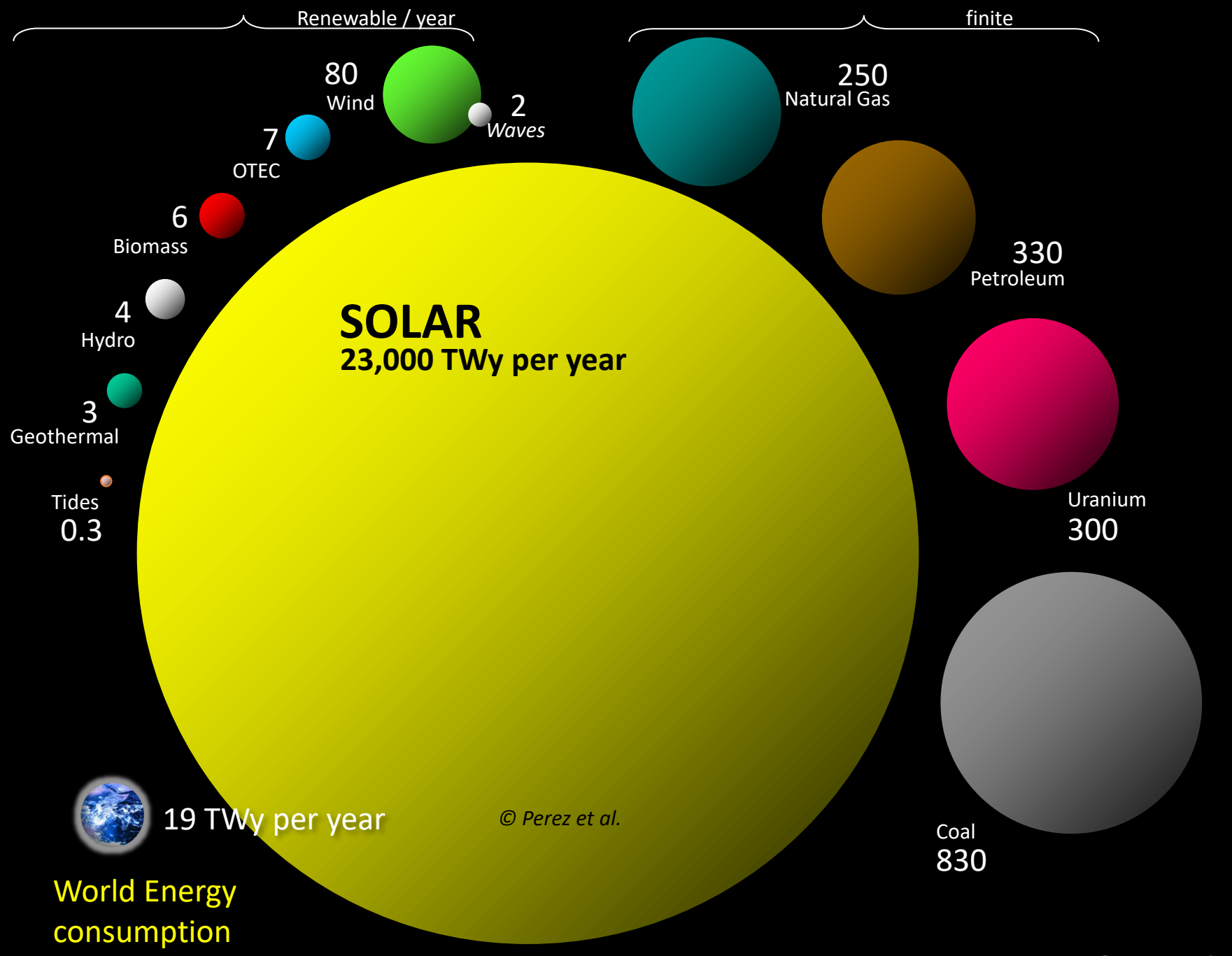
Almost 90% is traceable to energy consumption



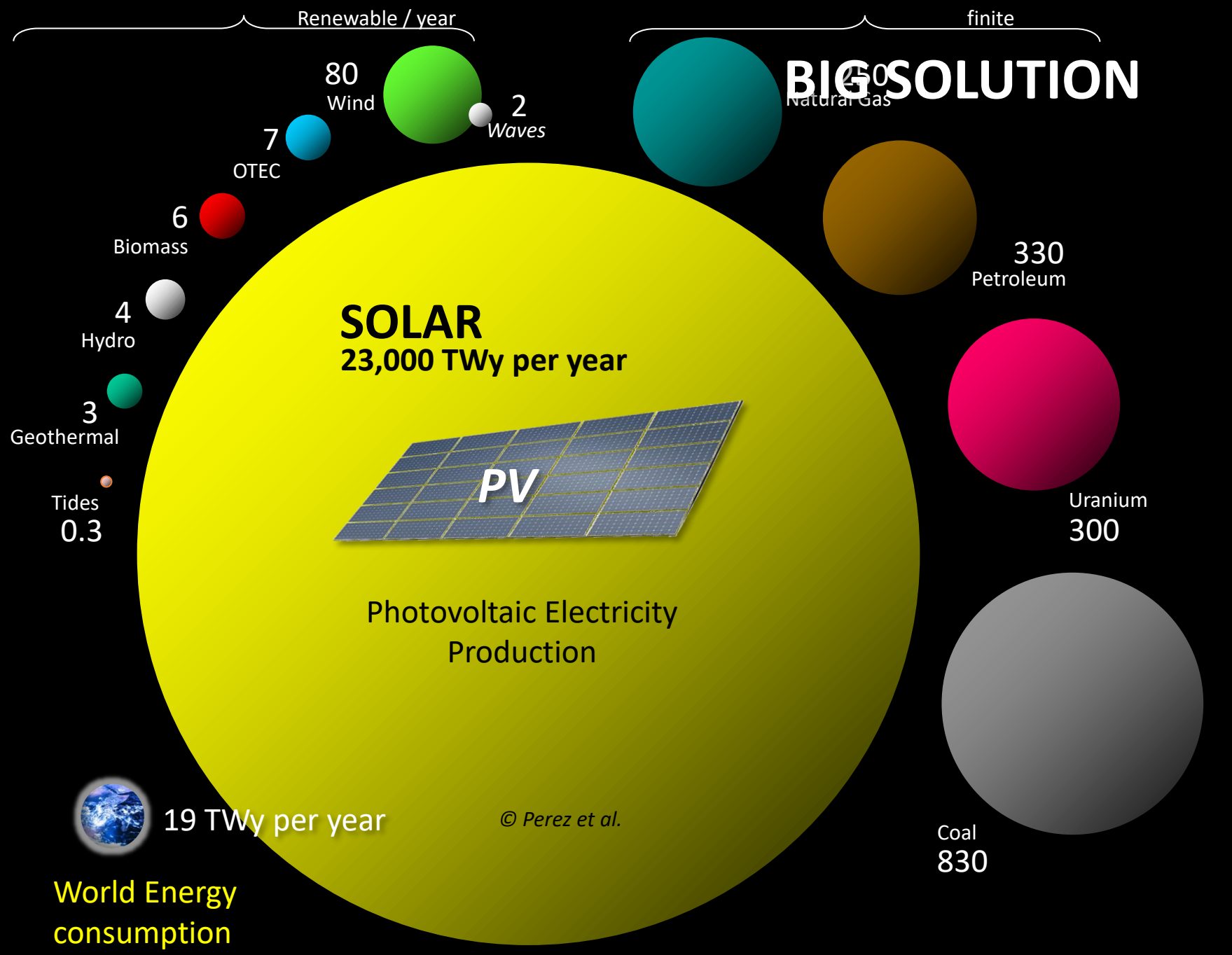


Green House Gas Emissions per Sector

World Energy consumption


Renewable / year
finite
80
Wind
2
Waves
7
OTEC
6
Biomass
4
Hydro
3
Geothermal
Tides
0.3
250
Natural Gas
330
Petroleum
Uranium
300
Coal
830
SOLAR
23,000 TWy per year
19 TWy per year
© Perez et al.
World Energy consumption

© Perez et al.,

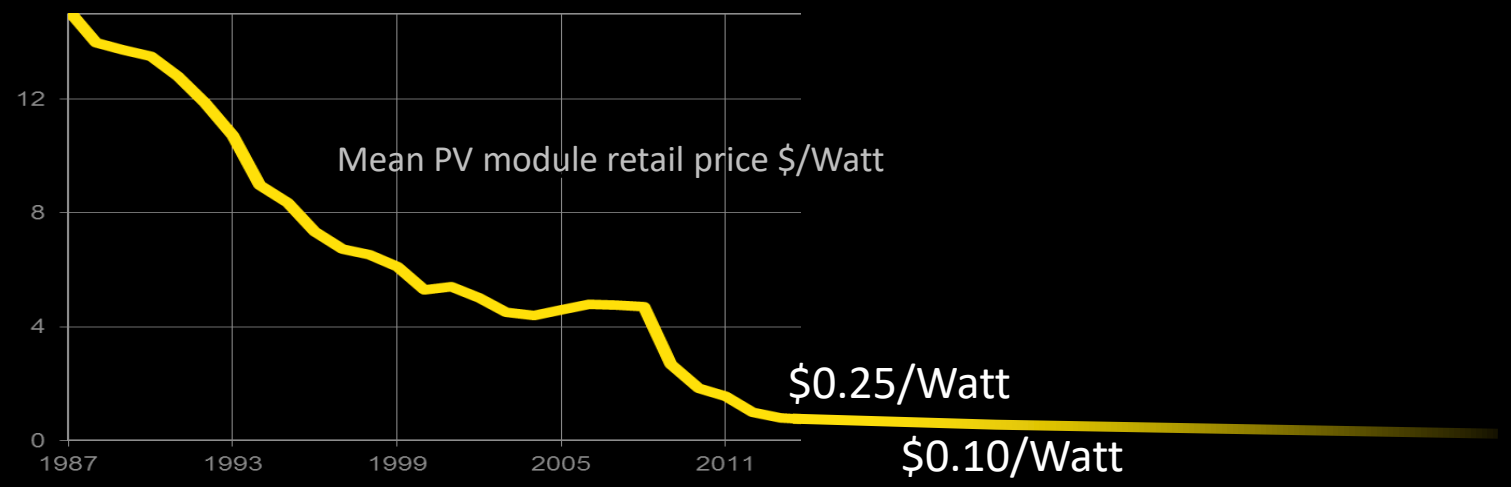

Renewable / year
finite
BIG SOLUTION
80
Wind
2
Waves
7
OTEC
6
Biomass
4
Hydro
3
Geothermal
Tides
0.3
650
Natural Gas
330
Petroleum
Uranium
300
Coal
830
SOLAR
23,000 TWy per year
PV
Photovoltaic Electricity Production
19 TWy per year
World Energy consumption
© Perez et al.

© Perez et al.,

"Solar PV is rapidly becoming the least expensive technologies to generate electricity on a pure energy (kWh) basis"

(Fortune Magazine)

BIG SOLUTION
CHEAP SOLUTION



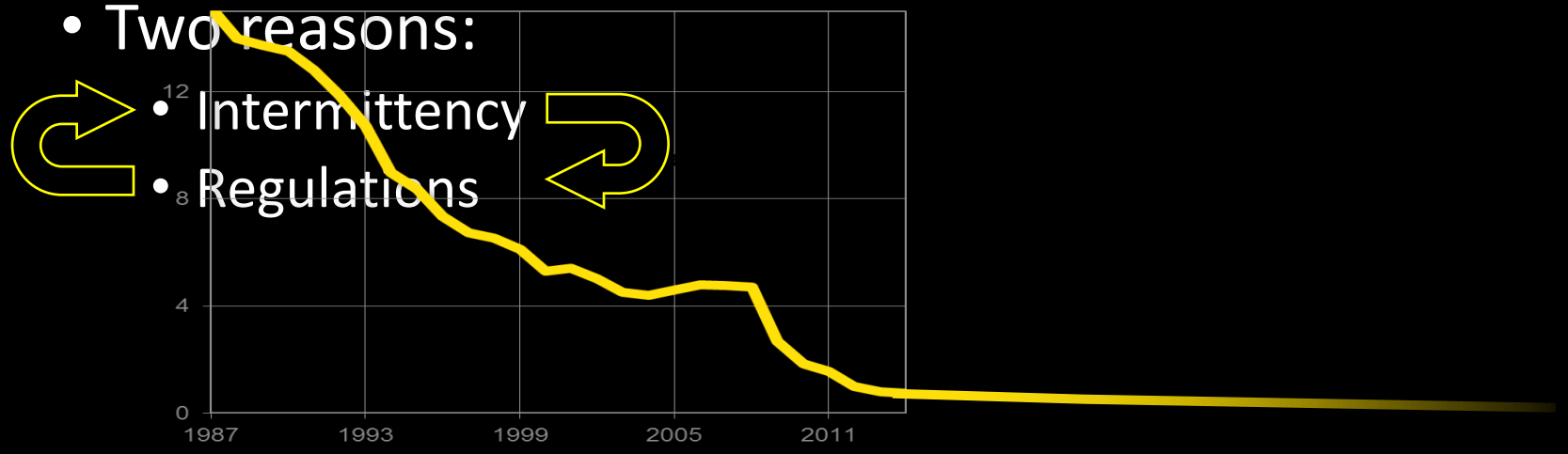
"Solar PV is rapidly becoming the least expensive technologies to generate electricity on a pure energy (kWh) basis"

(Fortune Magazine)

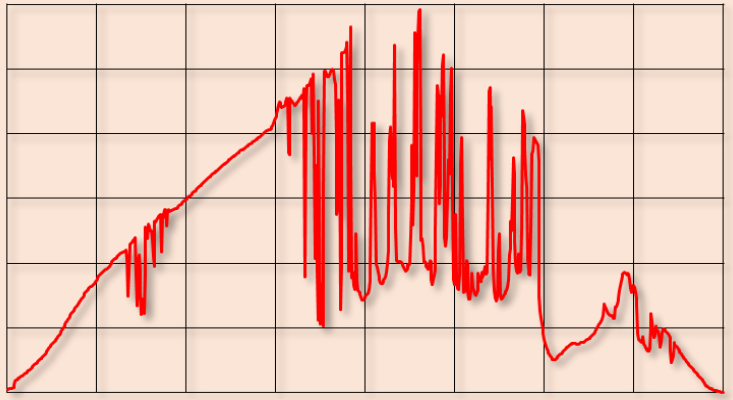
BIG SOLUTION
CHEAP SOLUTION

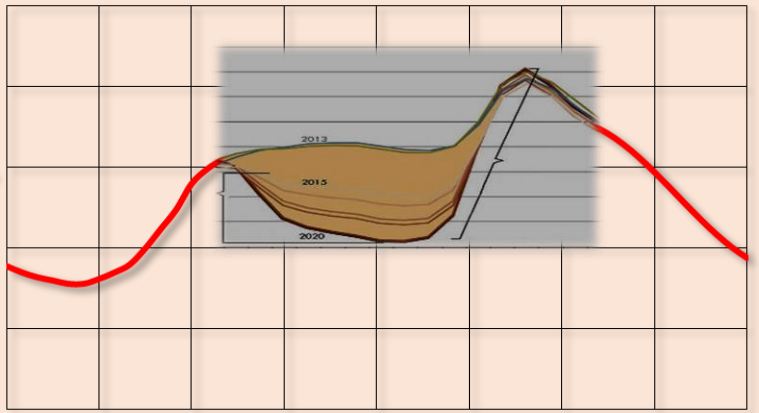
…. but not growing as fast and smartly as it could

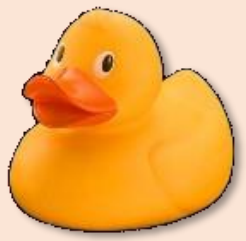
- Two reasons:
  - Intermittency
  - Regulations



INTRADAY







INTERMITTENT
Marginal Position

Utility - Solar industry opposition

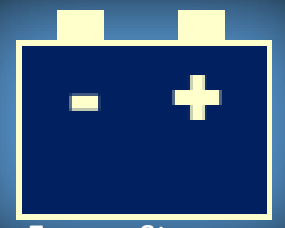
FIRM/DISPATCHBLE
Grid-Dominant Position

MULTI-DAY
SEASONAL

24/7/365

INTERMITTENT
Marginal Position

FIRM/DISPATCHBLE
Grid-Dominant Position

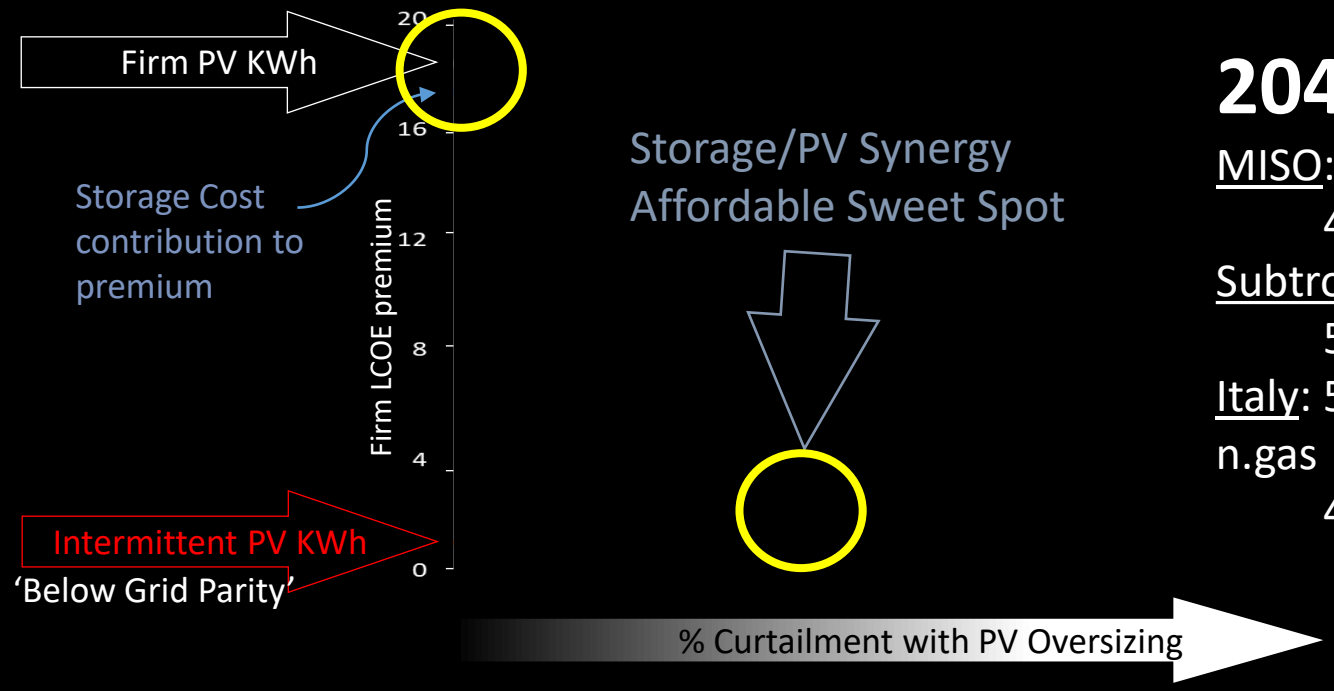


+ OVERBUILD & CURTAILMENT

Implicit storage

NOT MONETIZABLE

INTERMITTENT → ? **FIRM/DISPATCHBLE 24/7/365**



2040

MISO: 55% PV 40% wind 5% n.gas
4.6 cents / kWh

Subtropical Island Grid: 100% PV
5.5 cents /kWh

Italy: 52% PV, 30% wind, 10% hydro, 8% n.gas
4.4. cents per kWh

The solutions is more dependent on policy than technology

1. Monetize firm kWh instead of unconstrained kWh

Embed storage, curtailment and geographic dispersion in remuneration.

Firm/diapatchable PPAs

Evolve from current remuneration models e.g.,

- Energy production ppa's
- VDER
- NEM

The solutions is more dependent on policy than technology

1. Monetize firm kWh instead of unconstrained kWh
2. Firm power generation with respect to the grid

   Evolve from a customer-driven PV deployment and management process

   …to a grid-operator driven process

   This does not preclude developer/customer ownership

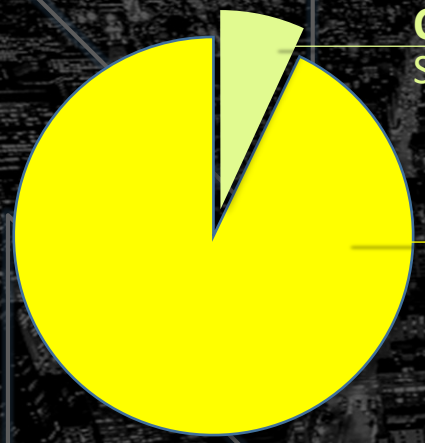
Customer-Driven Solar
Marginal Solar

Customer-Driven Solar
Marginal Solar

~ NET ZERO

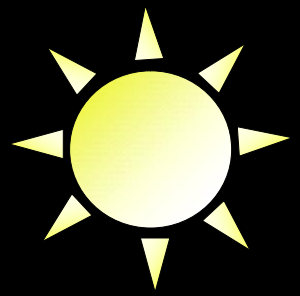
IS THIS THE BEST WAY TO BIG SOLAR?

Net Metering 30% FedITC 25% NYSITC NYS rebate $1/Watt EV Rebates Low-interest financing



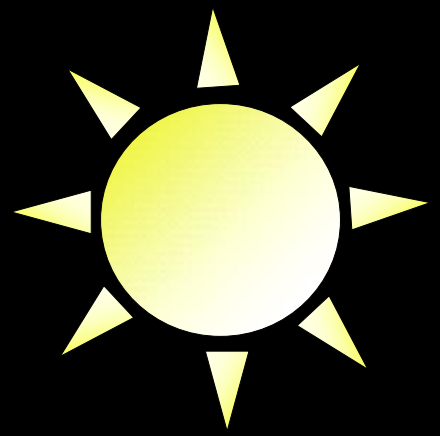
Customer-driven
SOLAR AT THE MARGIN FOR SOME

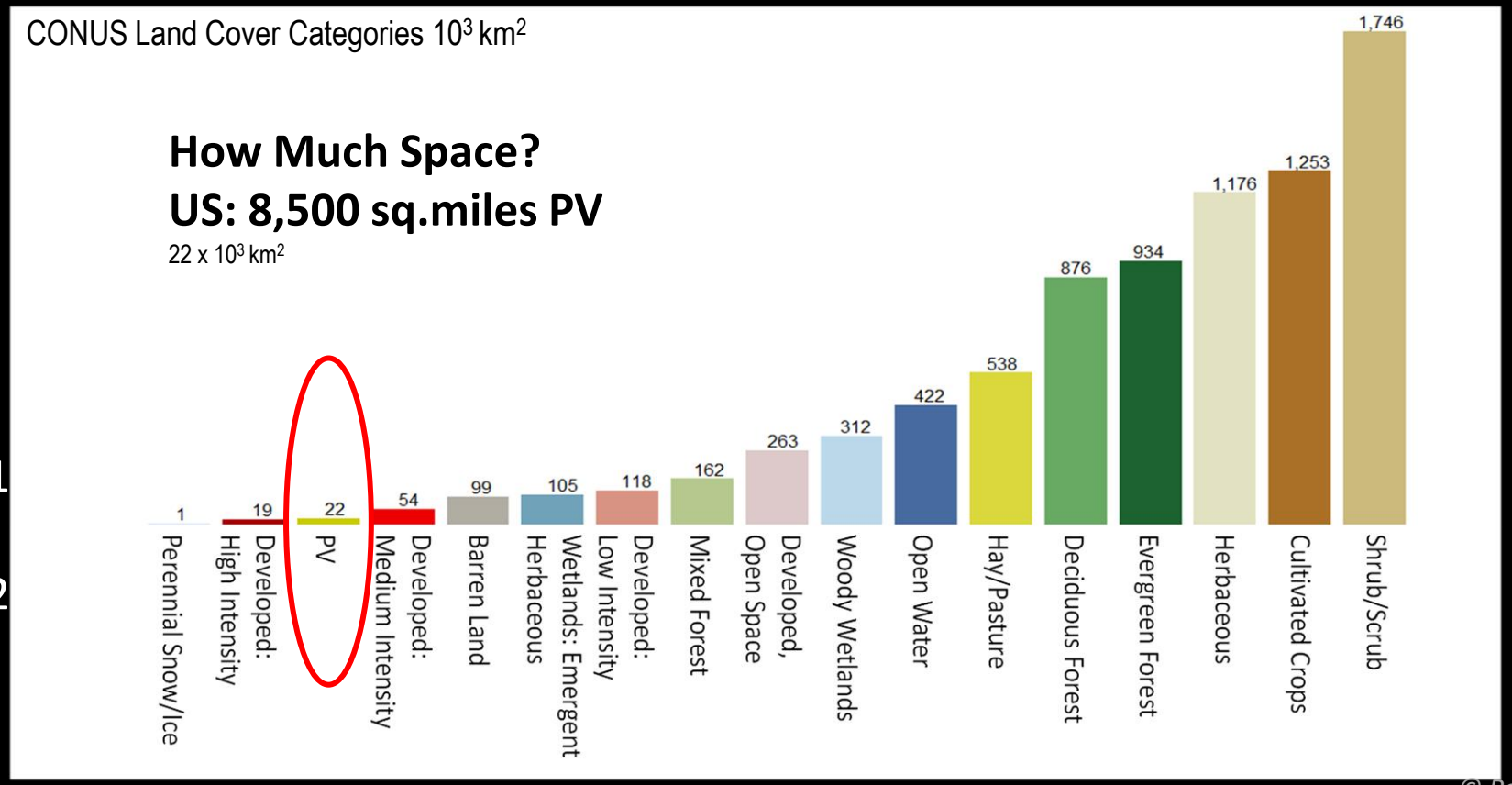
Cities, Industrial, Commercial
ABSENT: BIG SOLAR FOR ALL

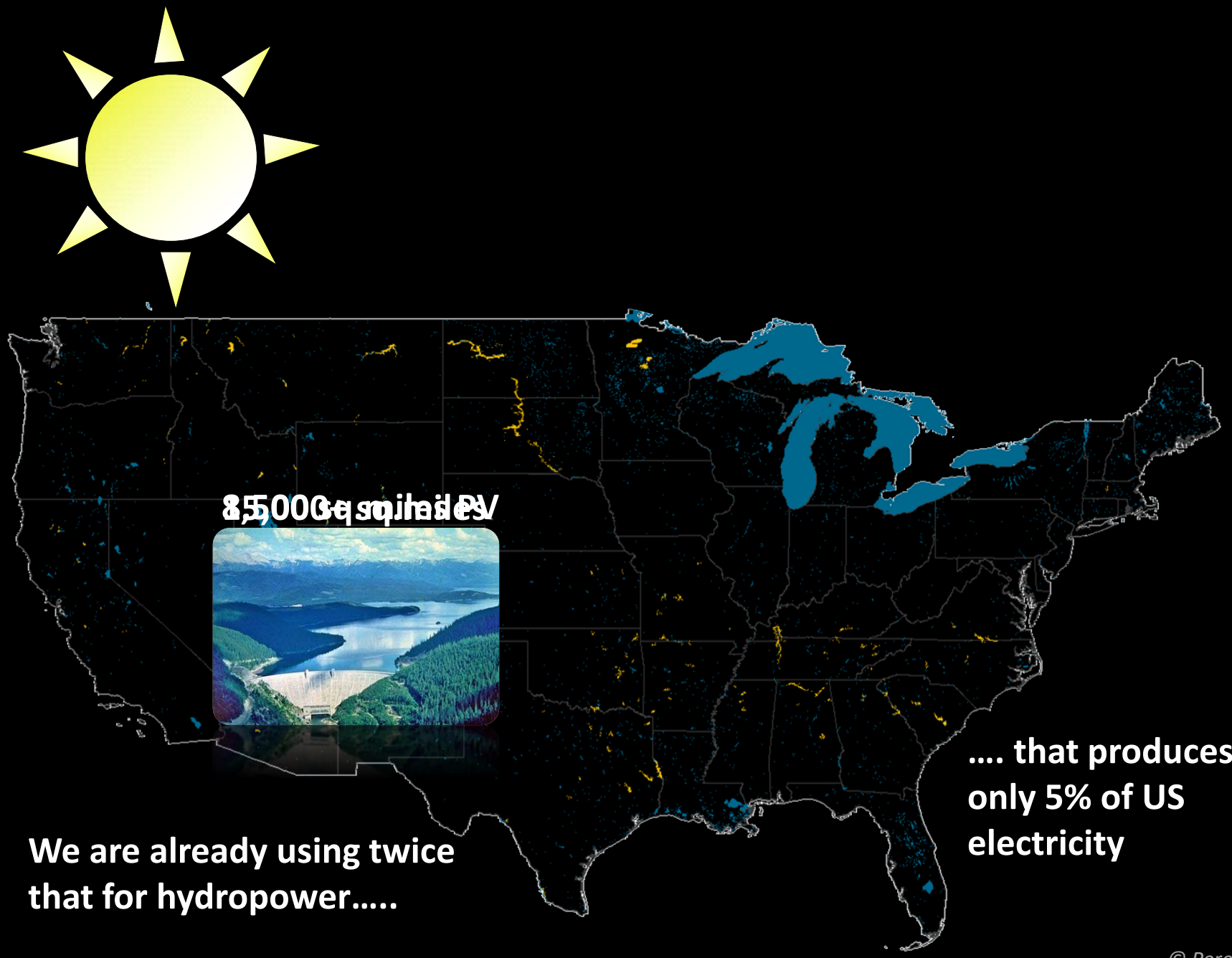


~~Marginal Solar~~
BIG SOLAR ?

1. Monetize firm kWh instead of unconstrained kWh
   Embed storage + overbuilding
2. Firm power generation with respect to the grid
   Grid operator management




CONUS Land Cover Categories 10^3 km^2
How Much Space?
US: 8,500 sq.miles PV
22 x 10^3 km^2
1
2
Perennial Snow/Ice 1
Developed: High Intensity 19
PV 22
Developed: Medium Intensity 54
Barren Land 99
Wetlands: Emergent Herbaceous 105
Developed: Low Intensity 118
Mixed Forest 162
Developed, Open Space 263
Woody Wetlands 312
Open Water 422
Hay/Pasture 538
Deciduous Forest 876
Evergreen Forest 934
Herbaceous 1,176
Cultivated Crops 1,253
Shrub/Scrub 1,746



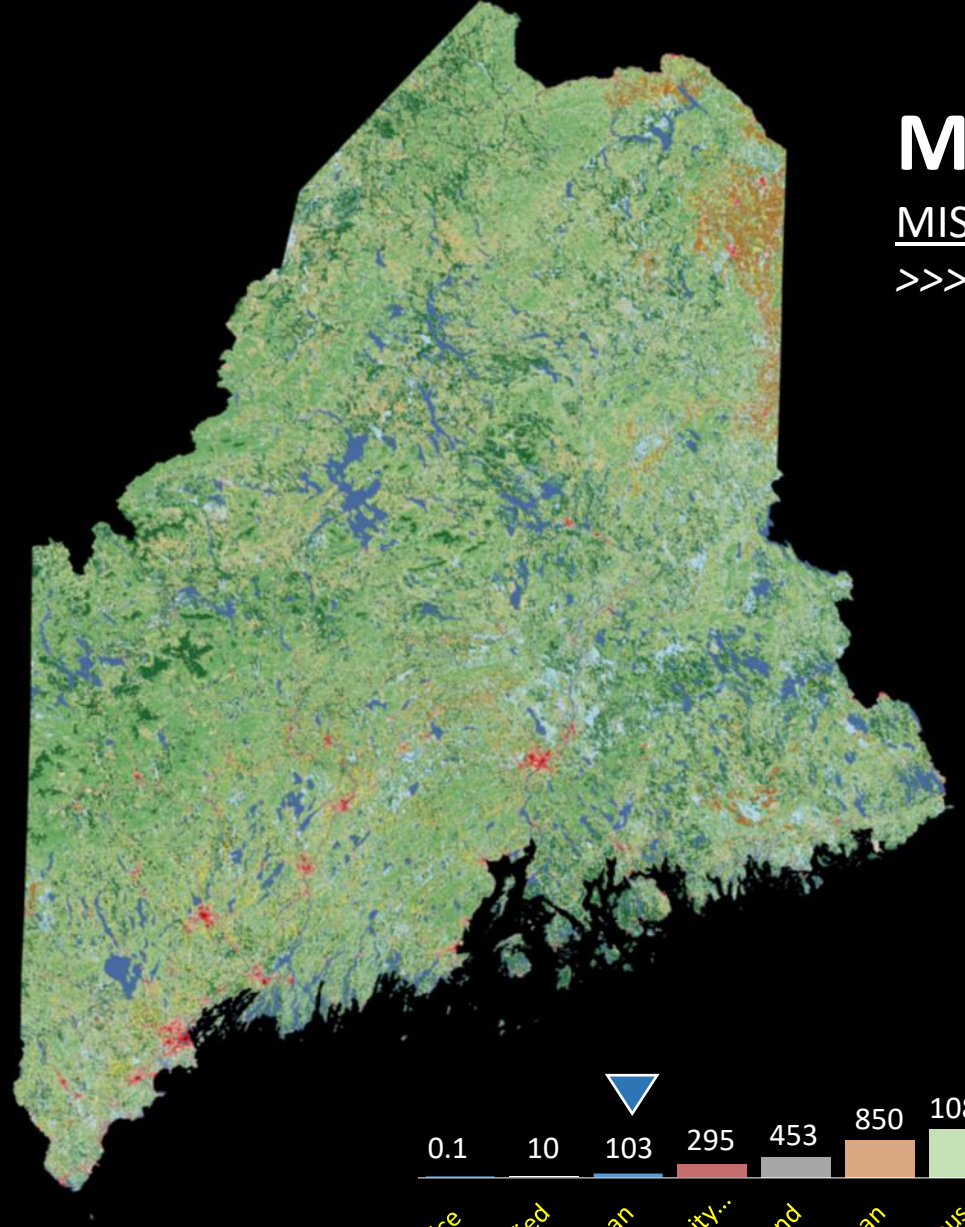
We are already using twice that for hydropower…..

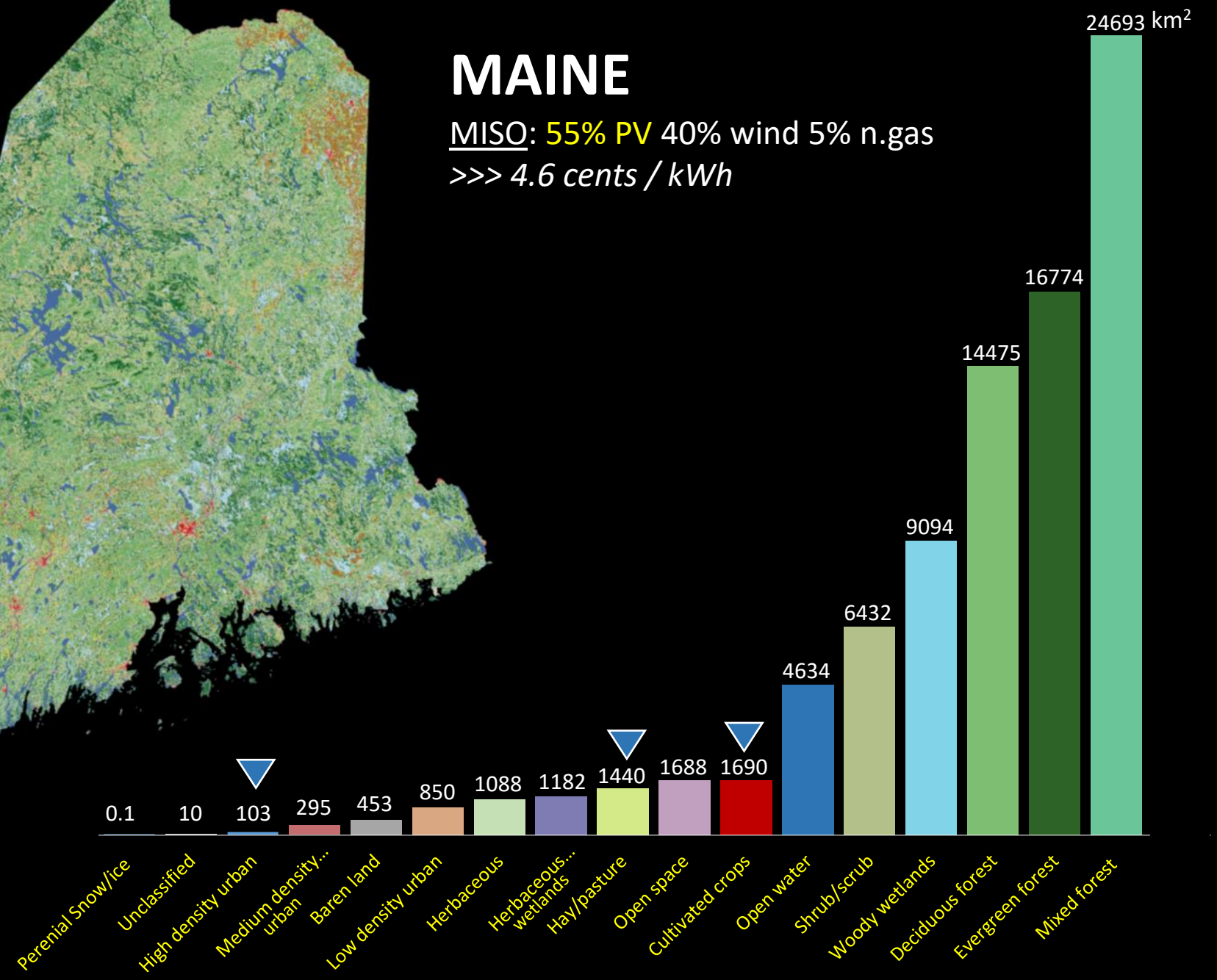
…. that produces only 5% of US electricity

MAINE

MISO: 55% PV 40% wind 5% n.gas

>>> 4.6 cents / kWh

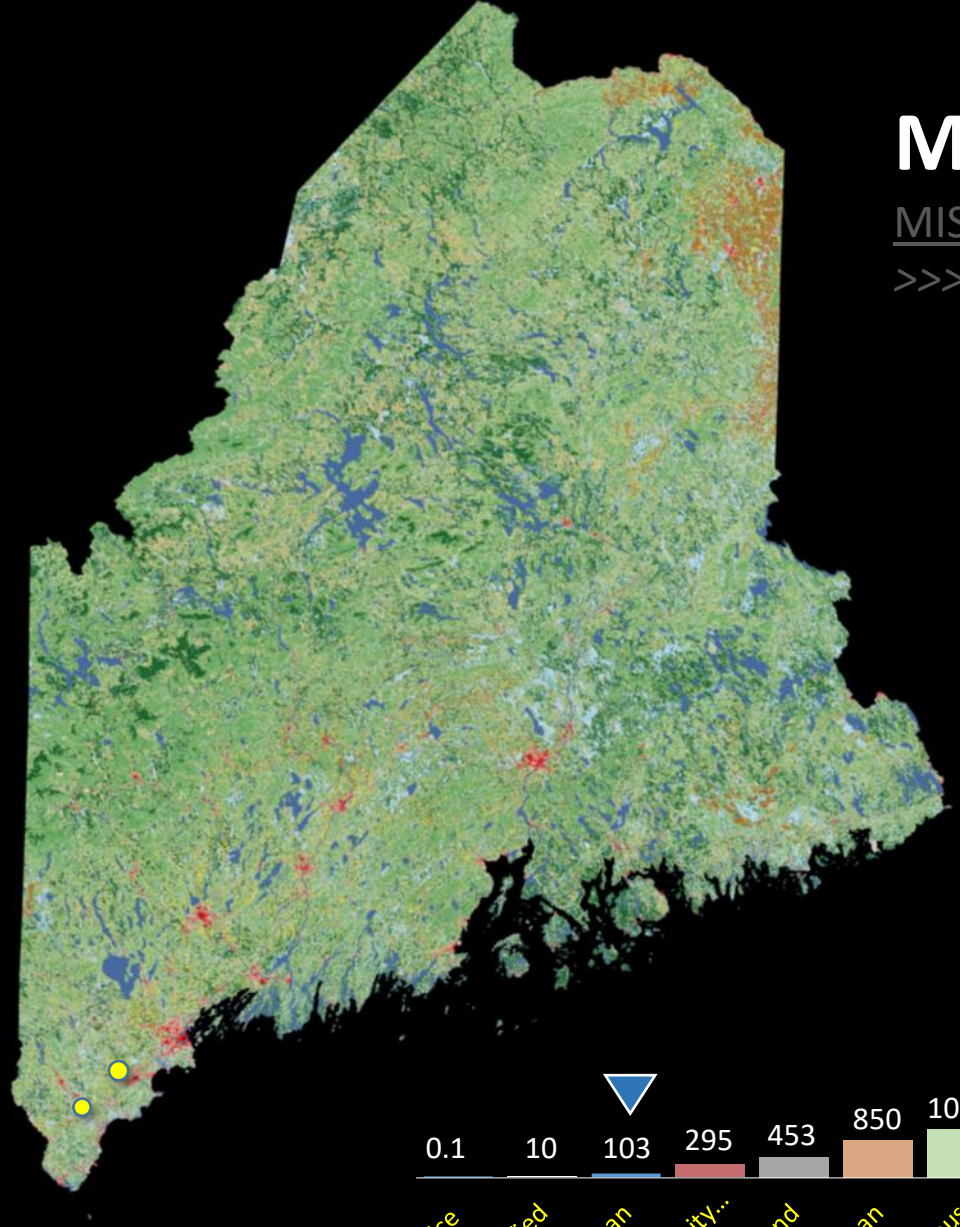


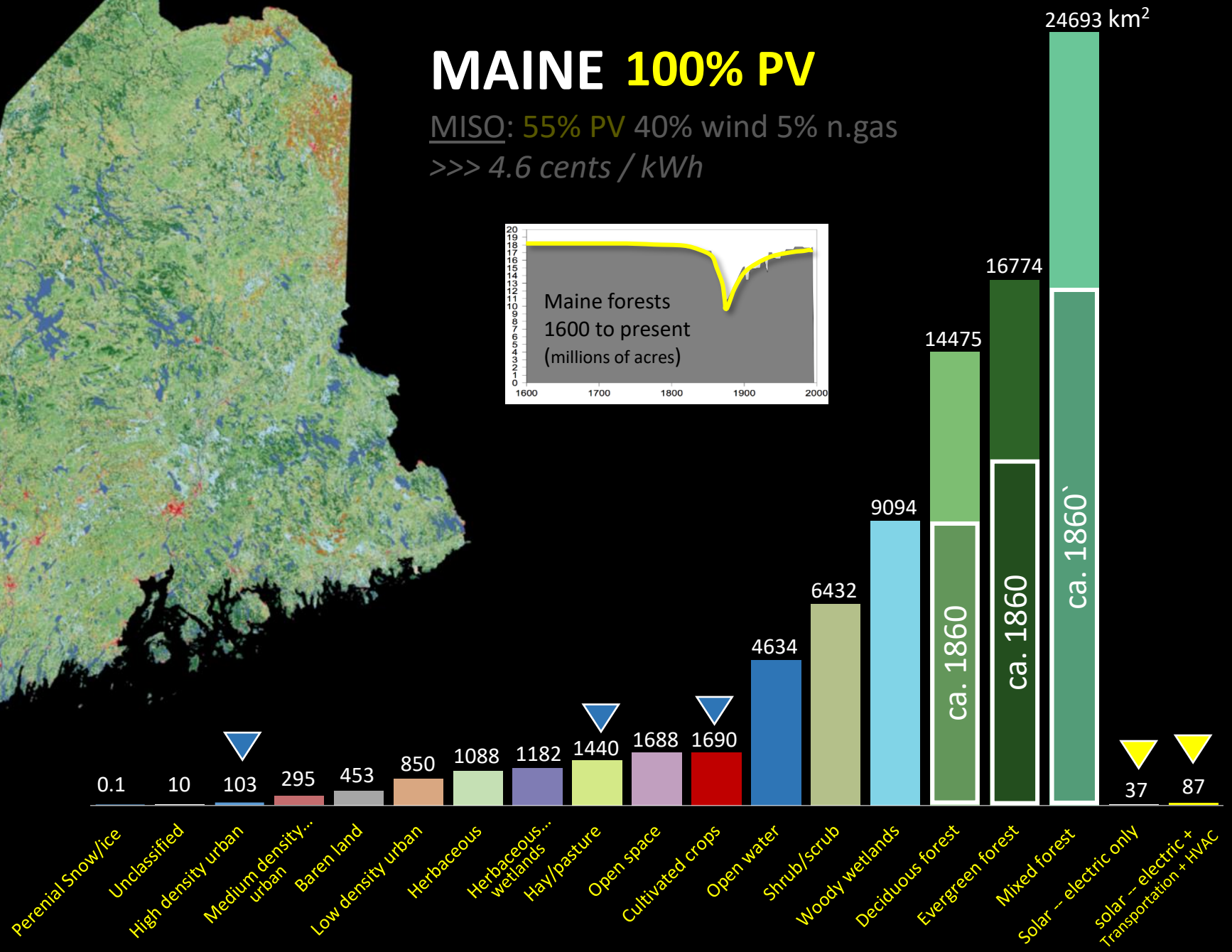


MAINE 100% PV

MISO: 55% PV 40% wind 5% n.gas

>>> 4.6 cents / kWh





MAINE 100% PV

MISO: 55% PV 40% wind 5% n.gas

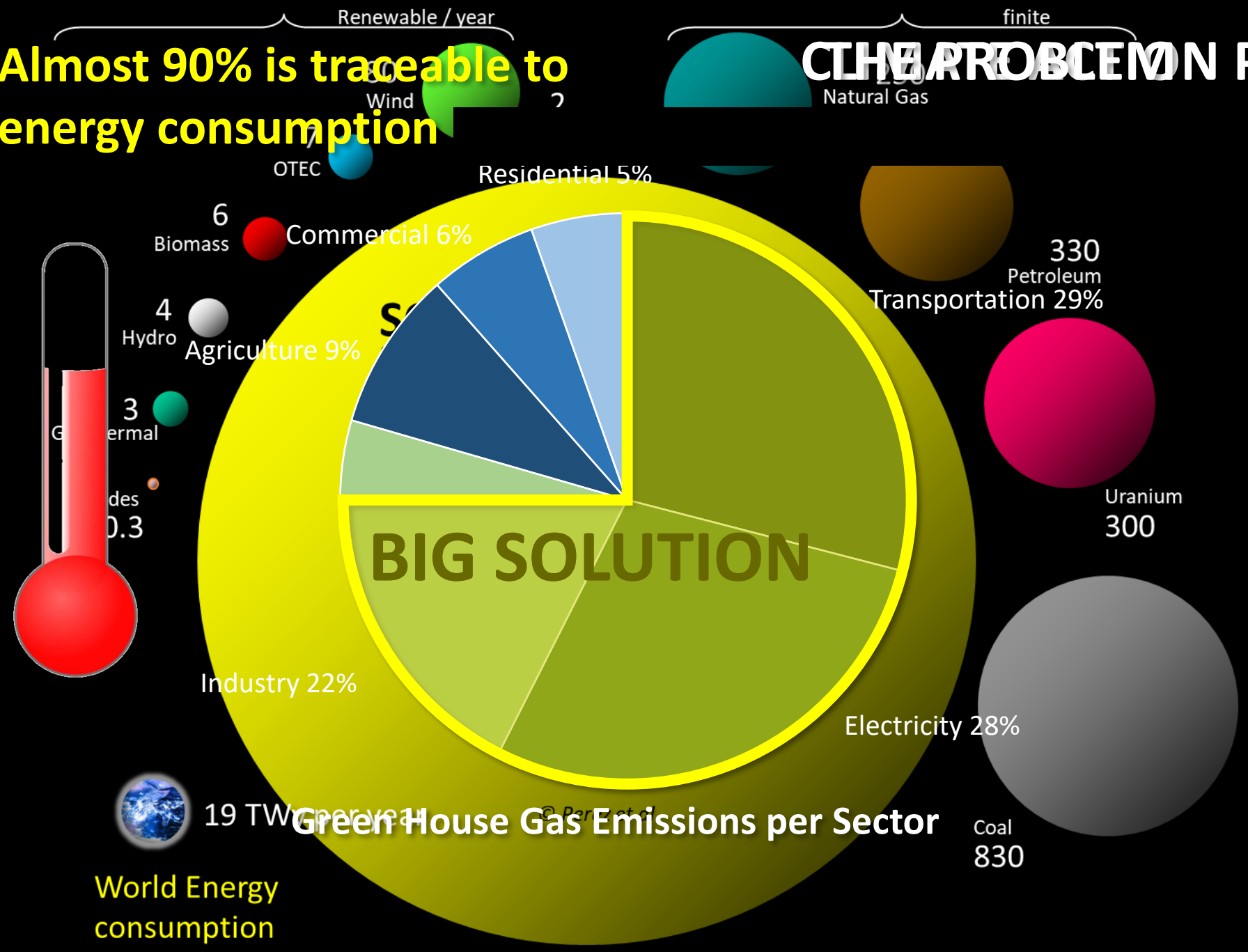
>>> 4.6 cents / kWh

1. Monetize firm kWh instead of unconstrained kWh
   Embed storage + overbuilding
2. Firm power generation with respect to the grid
   Grid operator management
3. Local/State/Regional/National planning: Where to deploy

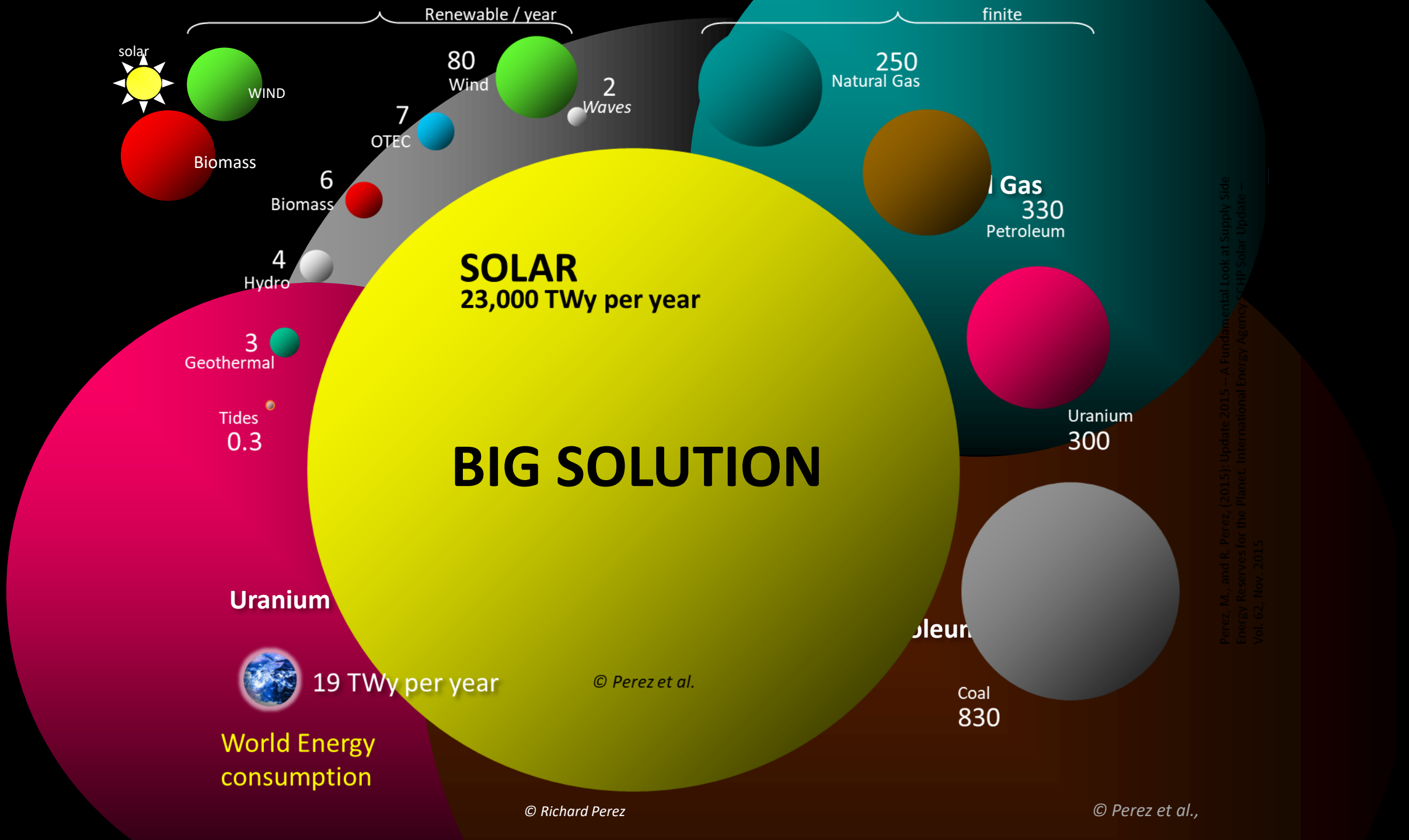
THE PROBLEM

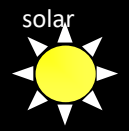
SOLUTION PLAN

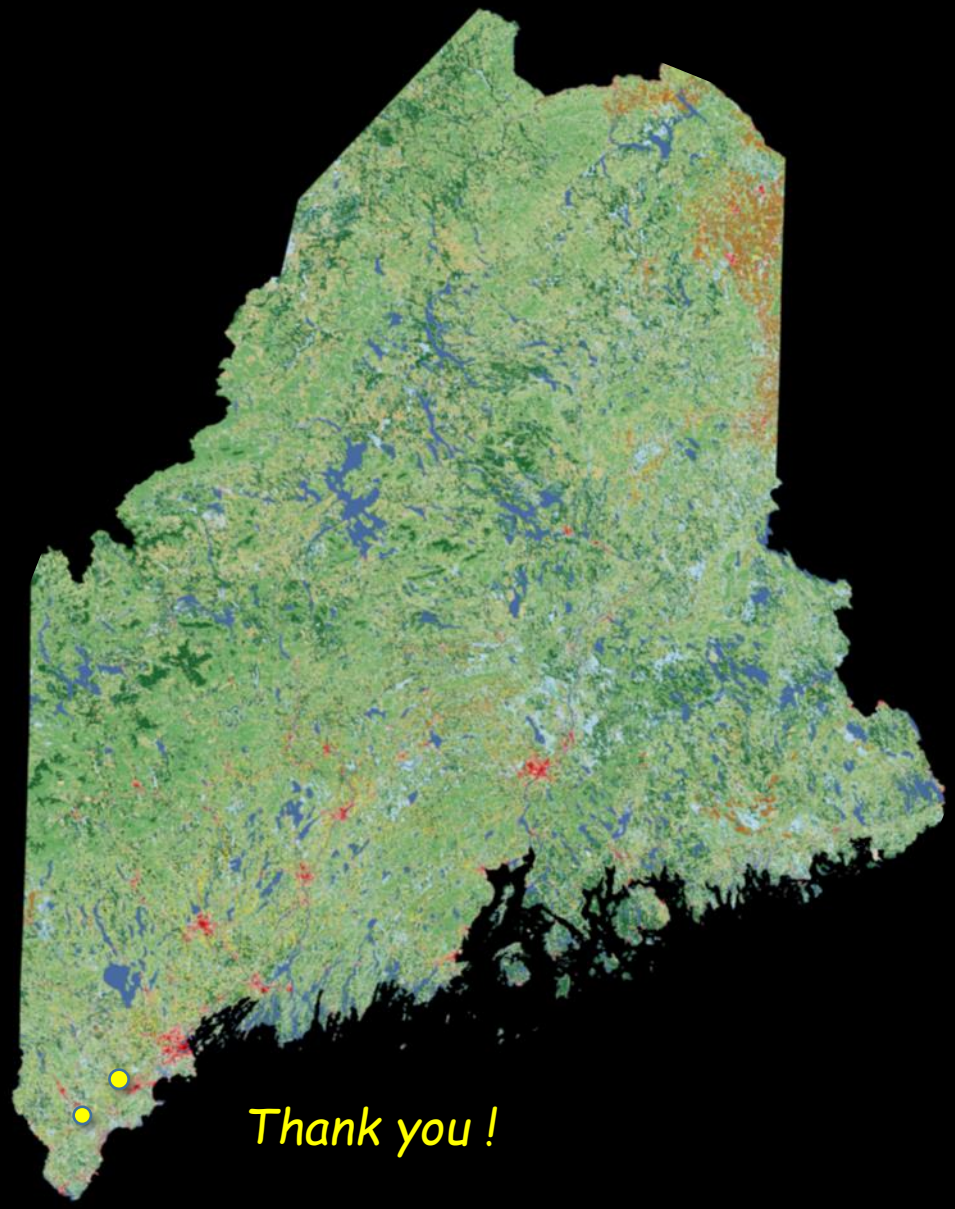
Almost 90% is traceable to energy consumption



© Perez et al.,


Renewable / year
finite
solar
WIND
Biomass
80
Wind
2
Waves
7
OTEC
6
Biomass
4
Hydro
3
Geothermal
Tides
0.3
250
Natural Gas
Gas
330
Petroleum
Uranium
300
SOLAR
23,000 TWy per year
BIG SOLUTION
Uranium
19 TWy per year
World Energy
consumption
© Perez et al.
Coal
830
© Richard Perez
© Perez et al.,
Perez, M., and R. Perez, (2015): Update 2015 – A Fundamental Look at Supply Side Energy Reserves for the Planet. International Energy Agency SHP Solar Update – Vol. 62, Nov. 2015





Thank you !