Photovoltaic Energy – Production and Storage Economics

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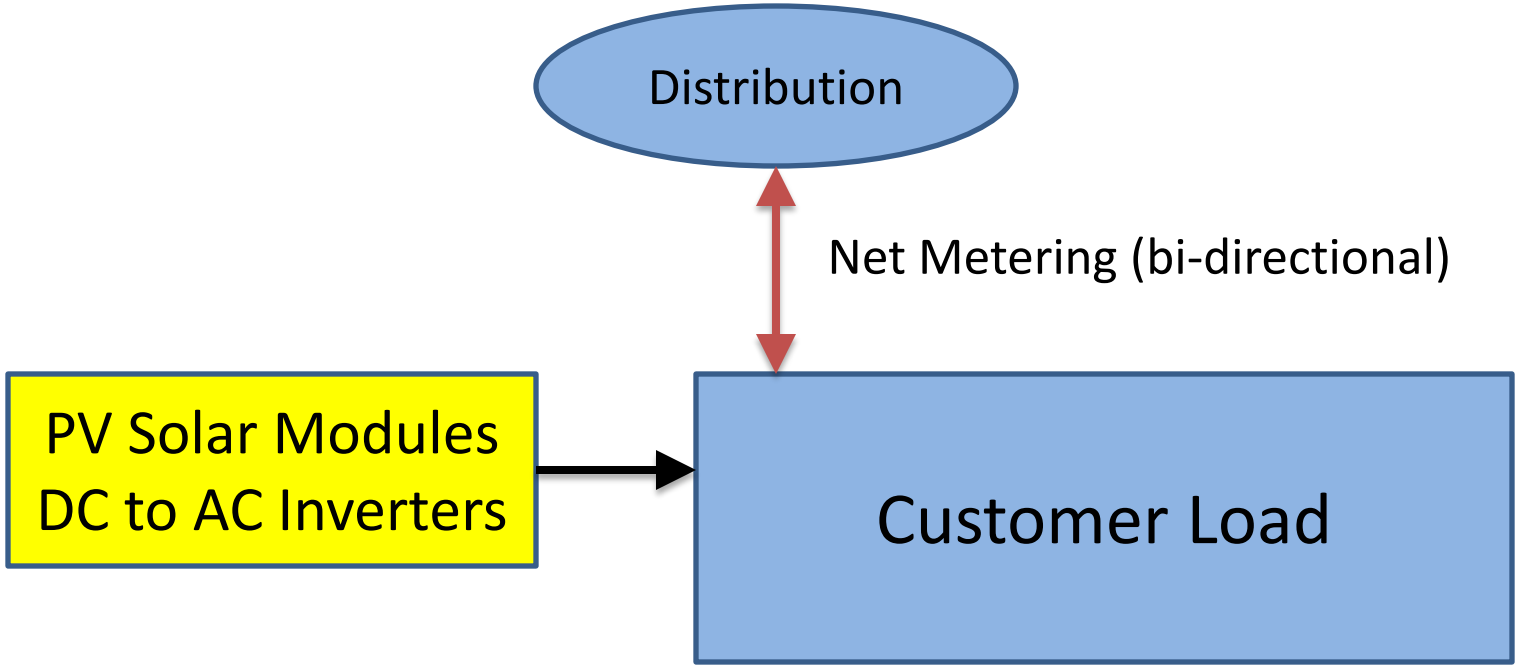
Outline

- Photovoltaics (PV) (2015)
  - Residential $3.00 per watt
  - Commercial $2.50 per watt
  - Community $2.00 per watt
  - Utility $1.60 per watt
- Storage (batteries)
  - Mobile
    - Electronics
    - Electric Vehicles (EV)
  - Stationary
    - Residential
    - Commercial
    - Utility

Advantages of PV Solar Power

- Produced at point of use
  - No utility network loads
  - No large distribution line load
- Environment effects
  - No noise
  - No CO2 production
  - Reduces individual Carbon Footprint
  - Silicon based panels have no toxic materials
  - No heat rejection to water or air
- Improved United States energy independence
  - Zero fuel cost
  - 25+ year life

Residential Photovoltaic



PV Financing (Residential)

- Outright Purchase ($3.00 per watt)
  - Highest return on investment
- Third Party Lease (Zero out of pocket)
  - Encouraged in some states, legal in most
  - 75% of current installations
- Community Solar
  - Buy a part of a larger array
  - Located away from residence

Public Enphase Systems

Worldwide more than 300,000 systems. Hawaii has 38,192, Alaska has 43

Swanson Phase 2 (9.1 kW) (2012)

Could be 15.2 kW with 330 watt panels (2016)

Green Key Village Net-Zero Houses

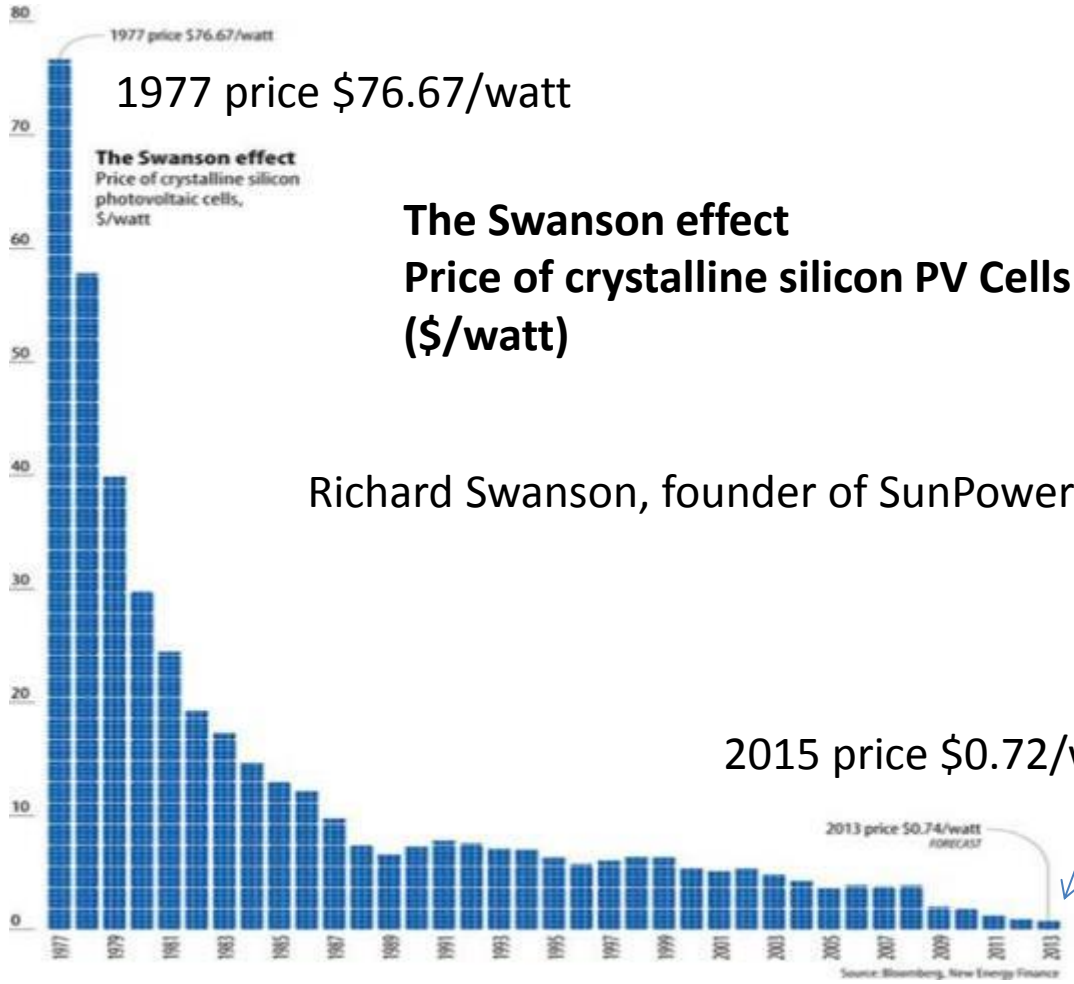
Planned 142 energy optimized houses in central Florida

“The Swanson Effect”

$70

$20

$10



1977 price $76.67/watt

The Swanson effect
Price of crystalline silicon PV Cells ($/watt)

Richard Swanson, founder of SunPower Corp.

2015 price $0.72/watt

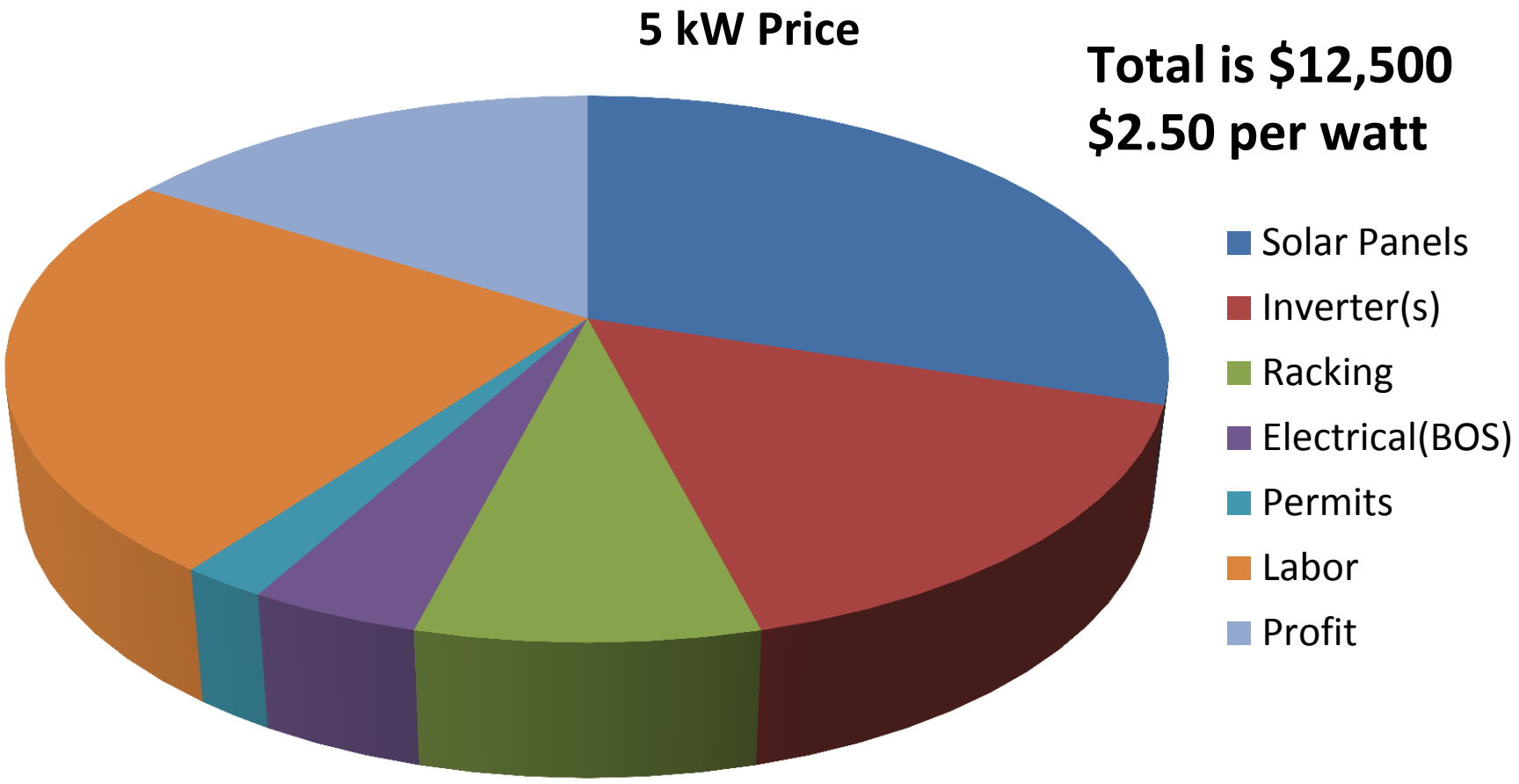
1977

2013

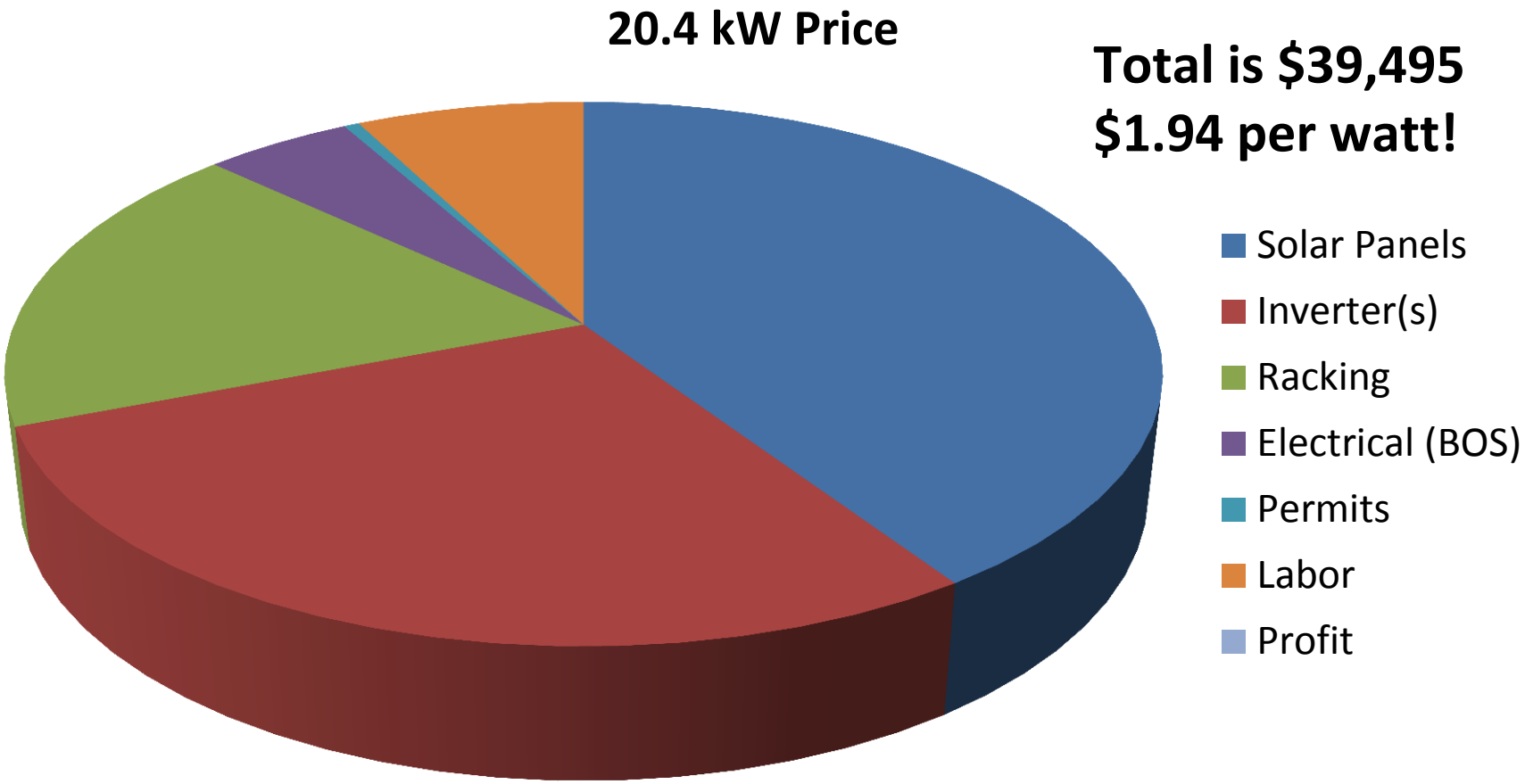
Factors behind rapid drop in price

- Increasing production
  - 20% drop for every doubling of production
- Raw material availability
  - Silicon panels
    - Aluminum frames
    - Silicon active layers
    - Silver wires
    - Glass covering
    - Composite backplane
- Automated factories (robotics)
- Produced near point of use (reduced shipping)

Breakdown of Current Price (2015)



Best Friends Animal Shelter (2015)



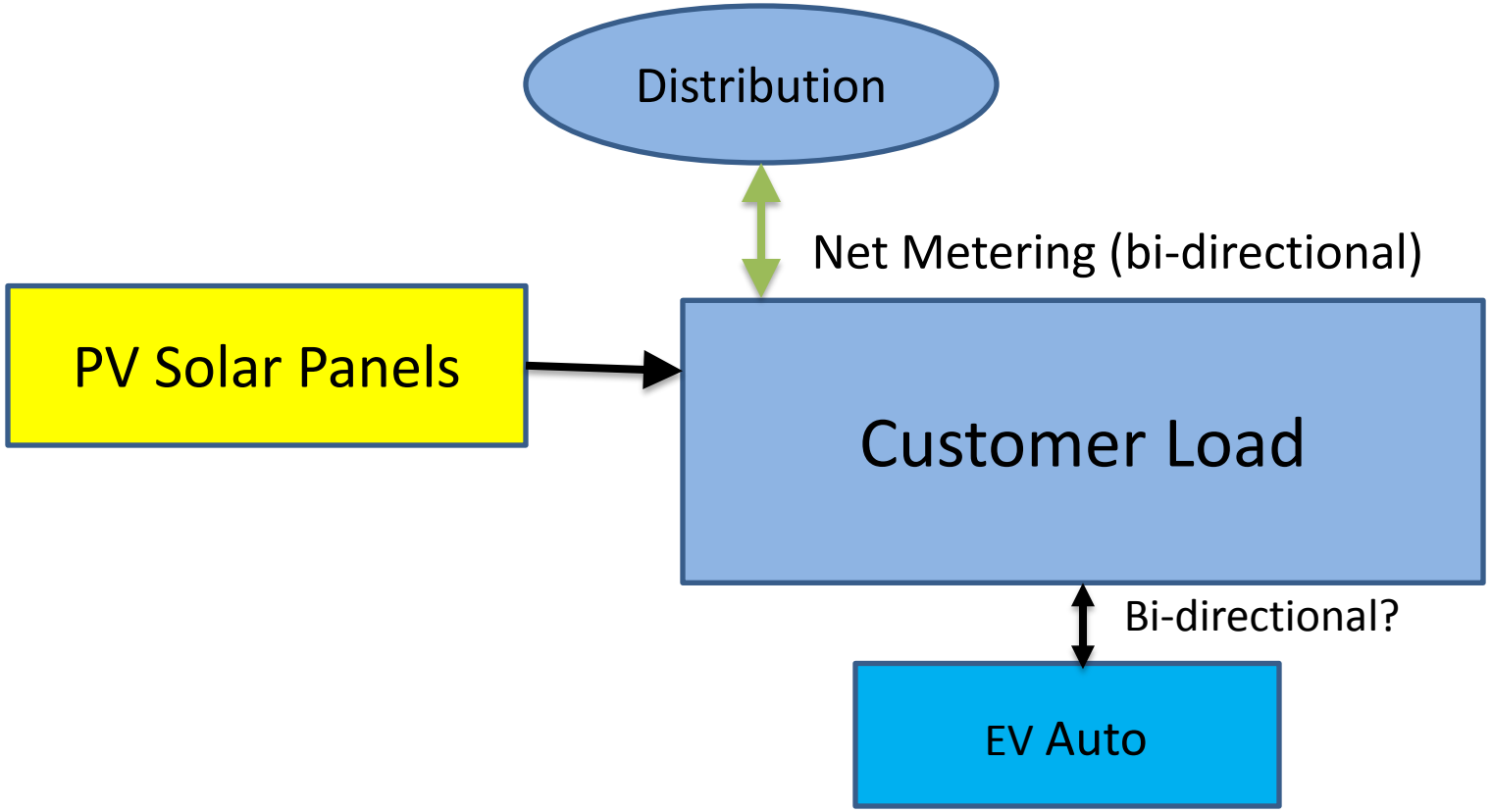
Non profit, no tax benefit, but Donor benefit (9% return equivalent)

Best Friends Sept. 2015

Chevy Bolt 2017

200 mile range
$35,000
18.4 kilowatt-hours of battery storage
120 kilowatt maximum discharge rate
Two electric motors, one for city, one to help at higher speeds

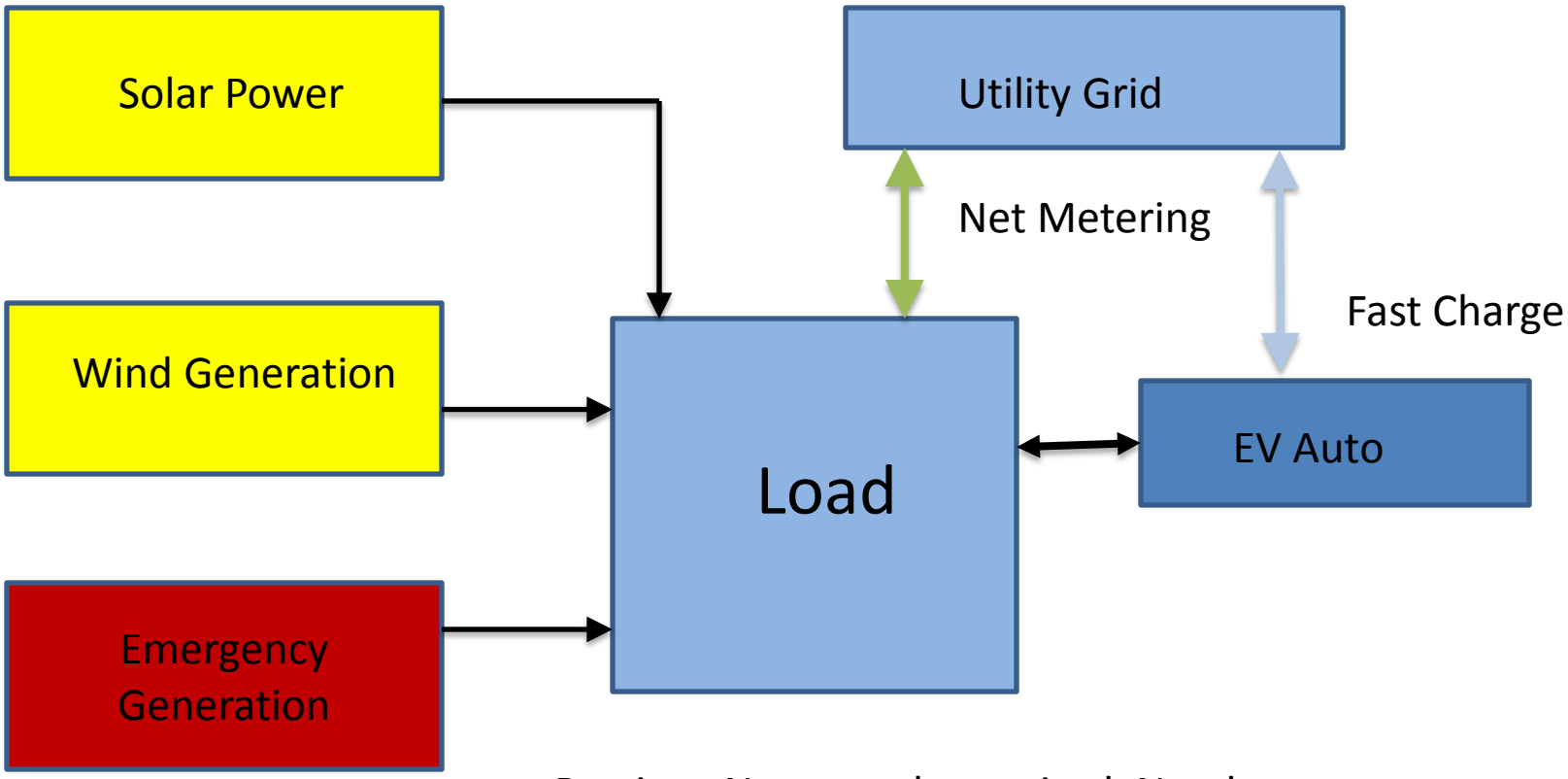
Electric Vehicle Customer



Residential Generation

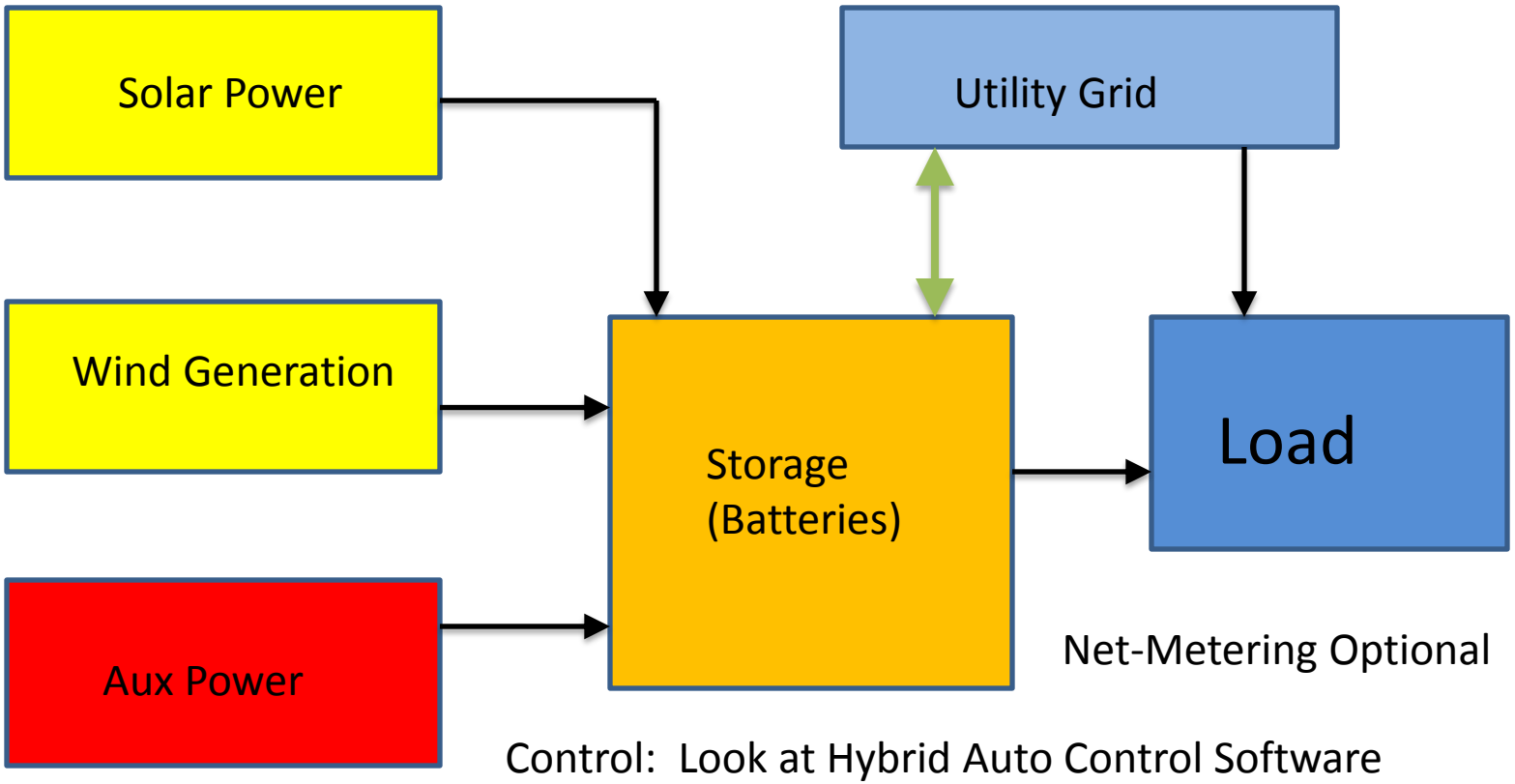
Natural Gas Fuel 18 kW $3957 20% eff. $0.21/kWh

Residential Power Components

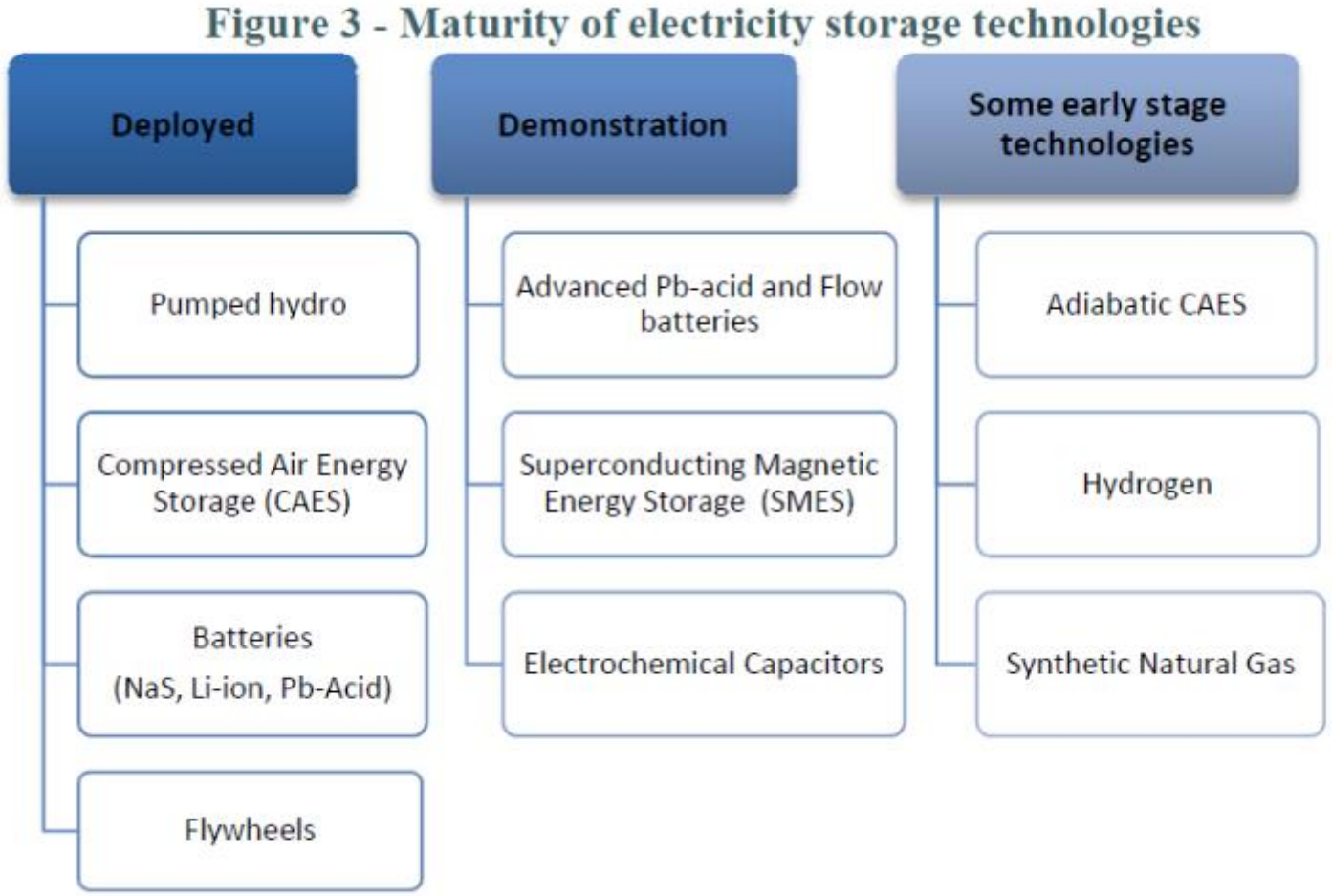


Passive: No controls required Needs to run without live grid for emergencies.

Residential Power Components (with storage)



Energy Storage Technologies



Grid Energy Storage, U.S. Dept. of Energy, December 2013

Some Battery Benefits

- Fast Response (Grid Stability)
- Bi-directional (Store or release energy)
- Provides variable load so generators can operate at optimum (full) load
  - Run generator at optimum to charge batteries
  - Turn off generator when batteries are charged
- Can store energy for long times (days)
- Can supply energy while slower generators come online (gas turbines, for example), adding to grid stability

Battery Markets

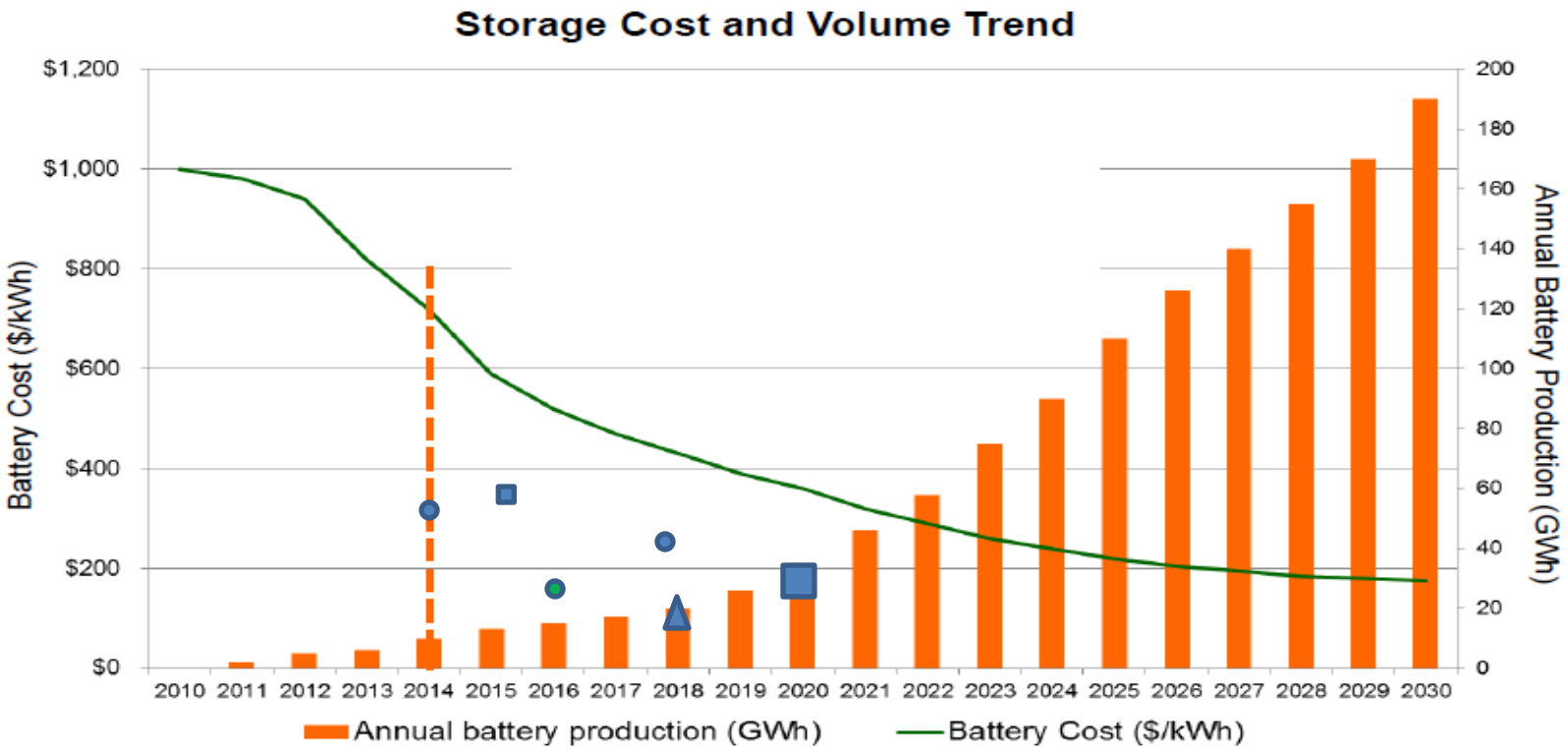
- Consumer electronics
- Electric Vehicles
- Residential PV backup/time shifting
  - Storage for electric vehicles
- Commercial Market
  - Peak shaving and/or demand charge reduction
- Utility Market
  - Peak shaving
  - Renewables integration (smoothing intermittency)
  - Ancillary services (Grid stability and security)
  - Transmission and distribution (T&D) upgrade deferral
  - Bulk Storage

Battery Price Data

- MIT Technology Review 3/30/15
  - May now be as low as $300 per kWh (2014) (lithium-ion)
  - Appear on track to reach $230 in 2018
- Tesla Nevada Super-factory goal
  - Goal is $250 per kWh (2017)
  - First year storage production sold out in days
- Eos Energy Storage (utility batteries)
  - $160 per kWh in volume for delivery in 2016
- Aquion Energy, Pittsburgh
  - Aqueous hybrid ion batteries
  - Currently $300 to $350
- Sakti3 startup in Michigan
  - Solid state batteries (slower response)
  - Target $100 per kWh
- Goldman Sachs estimate $125 to $200 by 2020
- Argonne National Lab goal $100 – failed with cycle life problems
- I predict $100 per kWh within five years
  - Remember the PV price curves and the factors behind it

A Storage Cost Projection

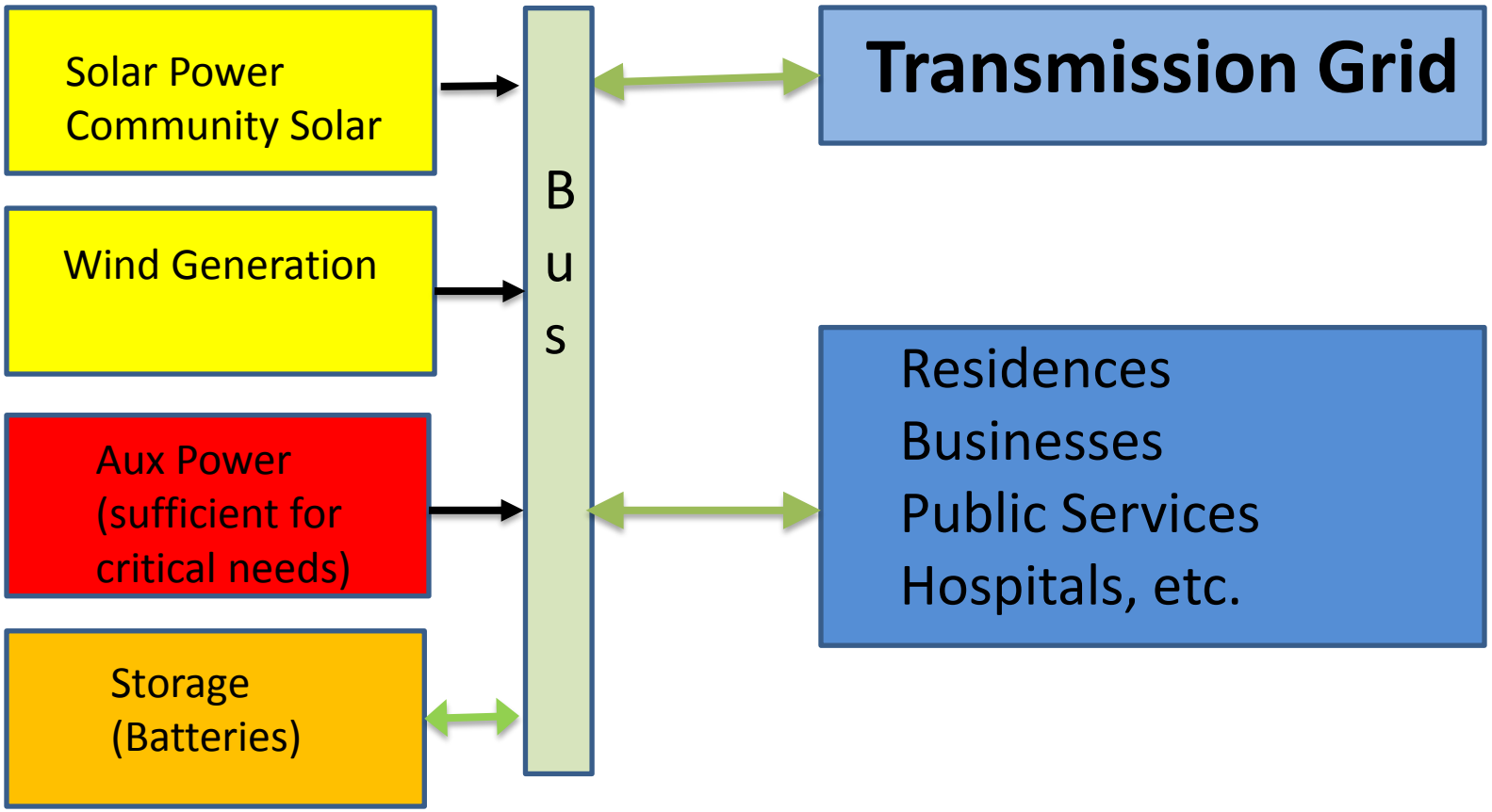
Storage Costs Following Similar Pattern (to PV)



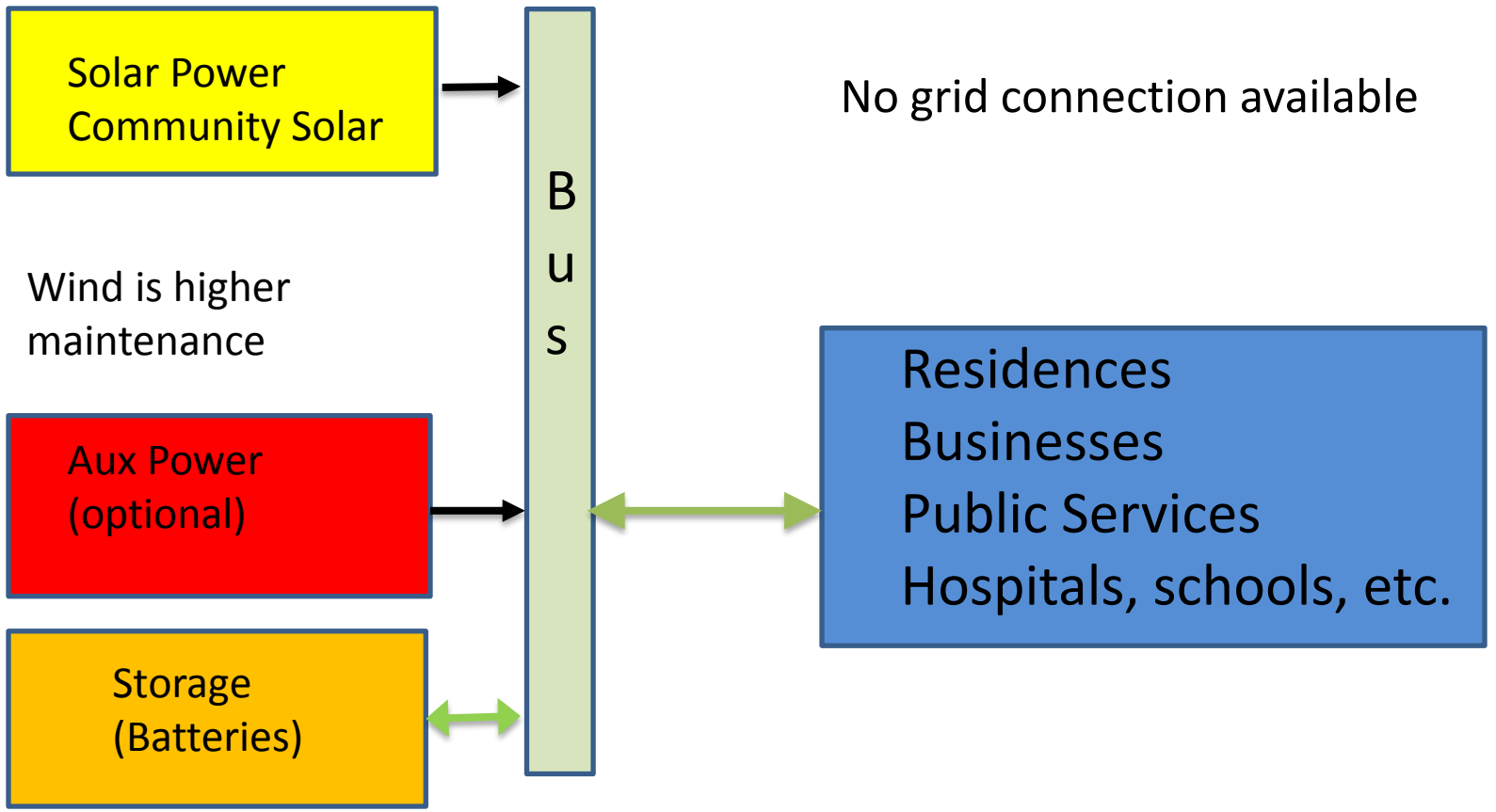
Source: Goldie-Scot, L.. (2014) "European End-User Storage: A Battery In Every Home?", BNEF.

SunEdison®

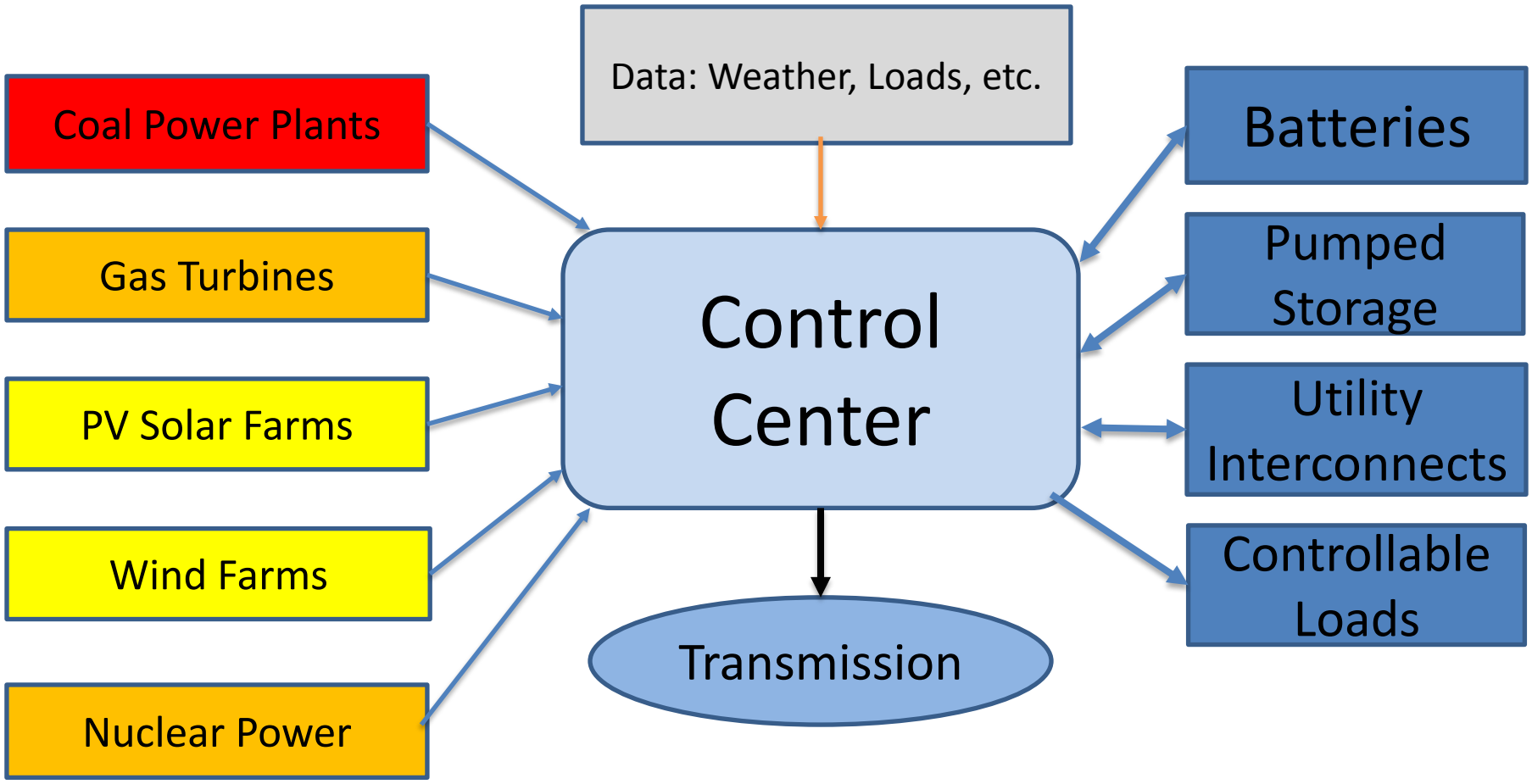
Local Micro-Grid Power Components



Rural Micro-Grid Power Components



Modern Energy Company



Utility Opportunities

- Solar fields can be used as a very responsive grid resource
  - Operate field at percentage of maximum (50%)
  - Add or subtract strings to adjust production
  - PV can respond in fractions of a second
  - My Ford Fusion battery maintains a 50% charge
    - It can absorb breaking energy by charging
    - It can use stored energy to run in EV mode

Utility Opportunities

- Batteries can be used in conjunction with gas turbines to cover the (minutes) lag as the turbines are put online or taken offline.
- Refer back to the Ford Fusion battery
- How big does the battery bank need to be to cover the energy production of the gas turbine for the startup interval? At what cost?

Utility Opportunities

- Batteries are stabilizers for the grid
- What is value vs battery capacity?
- Per the previous slide, they only have to cover the interval for the next resource (usually gas turbines).
- Gas turbines can stabilize the wind and solar resources
- Larger batteries may replace peaking gas turbines

Summary

- Residential/Commercial PV Solar Power is ready for wide application
  - Cost effective if:
    - Behind the meter
    - Net metering is available
    - Electric Marginal Cost > $0.10 per watt
- Batteries are the last big piece
- Changes are happening fast!
- Questions?