Solar, Storage, Stochastics and the Rebirth of ATM

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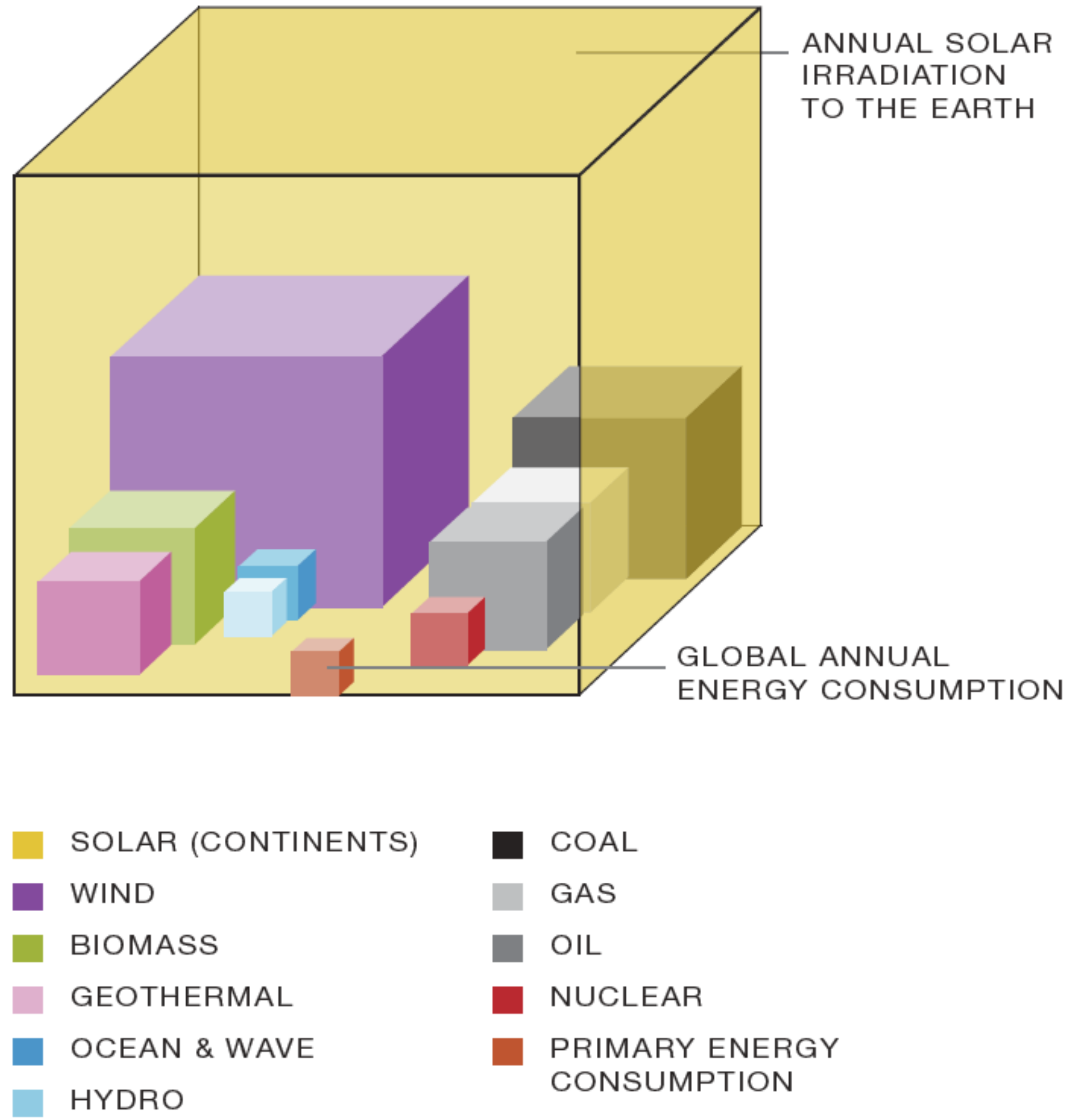
University of Waterloo

July 11, 2014

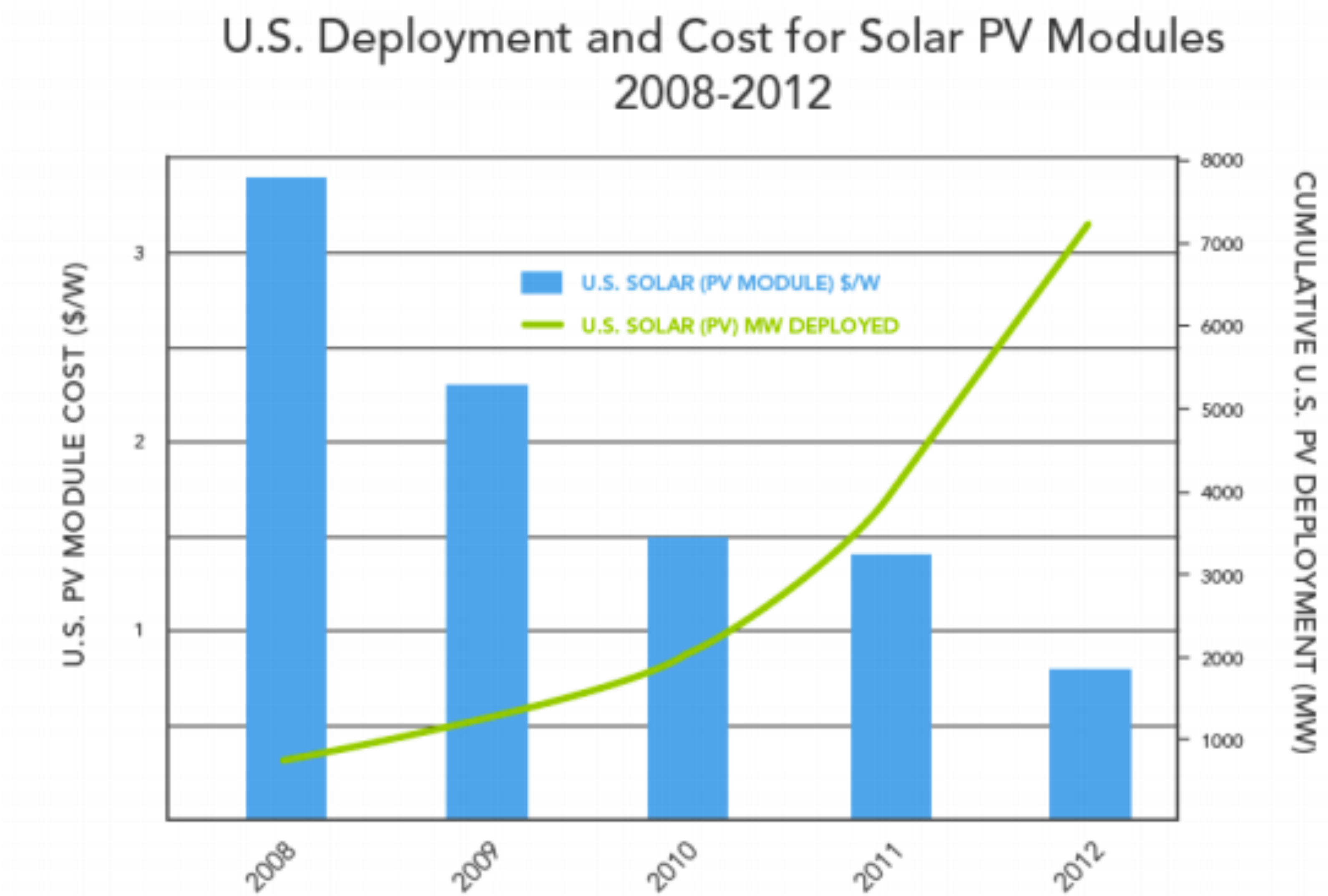
How long can this be sustained?

Alternatives



FOSSIL FUELS ARE EXPRESSED WITH REGARD TO THEIR TOTAL RESERVES WHILE RENEWABLE ENERGIES TO THEIR YEARLY POTENTIAL.

source: DLR, IEA WEO, EPIA's own calculations.



greentech.com

Global cumulative installed PV capacity in MW

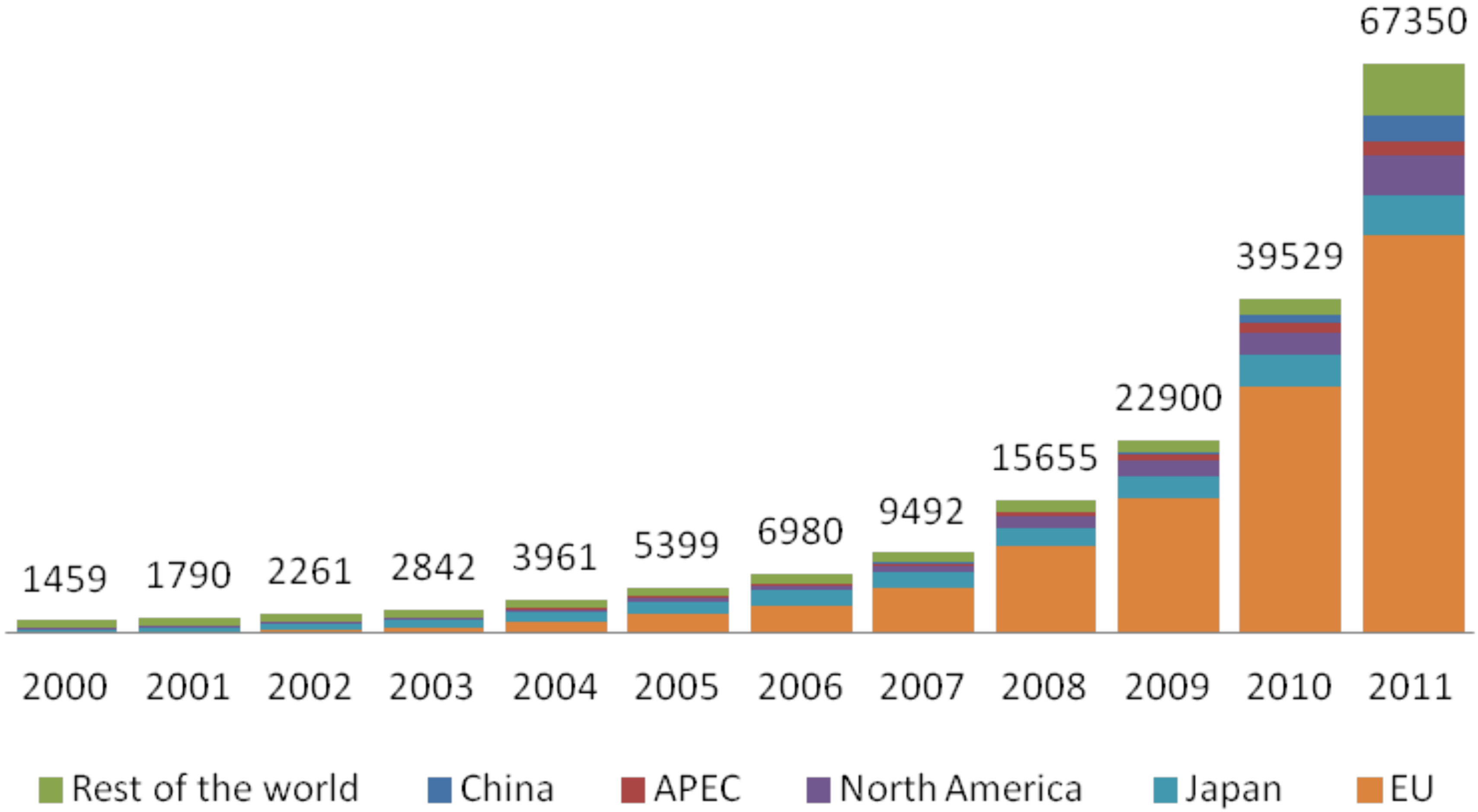
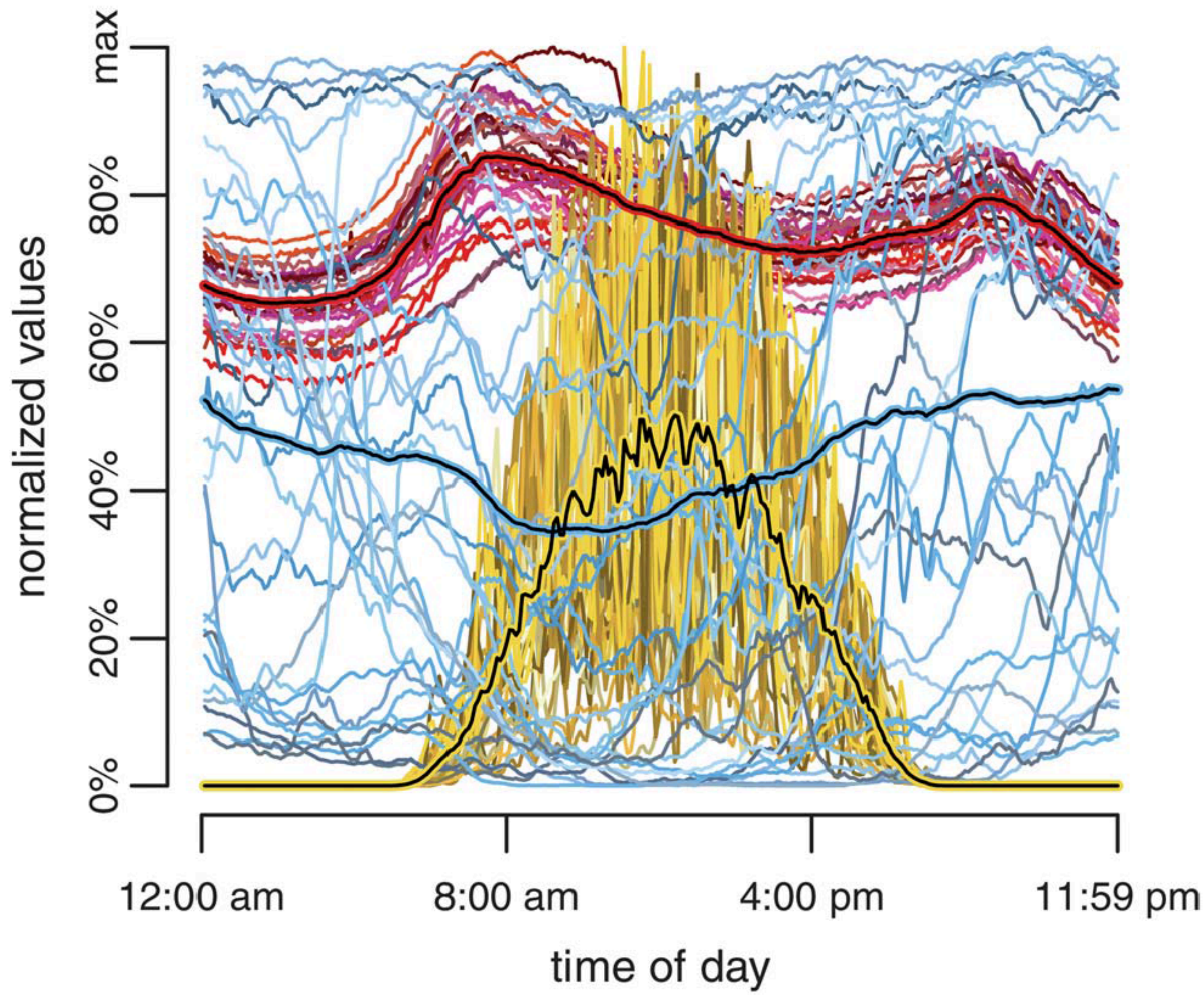


Table showing average cost in cents/kWh over 20 years for solar power panels

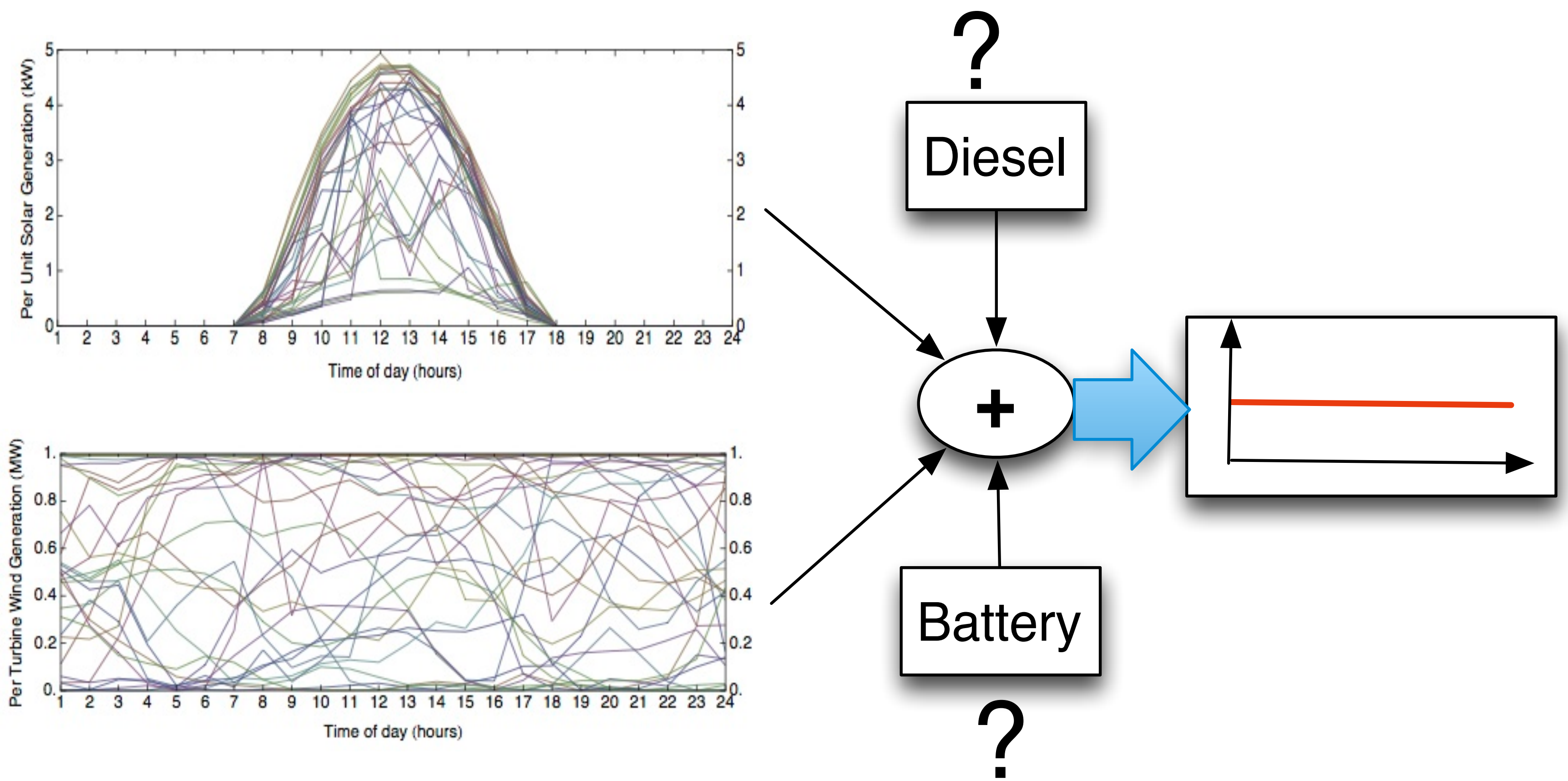
Cost	Insolation								
	2400 kWh/kWp·y	2200 kWh/kWp·y	2000 kWh/kWp·y	1800 kWh/kWp·y	1600 kWh/kWp·y	1400 kWh/kWp·y	1200 kWh/kWp·y	1000 kWh/kWp·y	800 kWh/kWp·y
200 $/kWp	0.8	0.9	1.0	1.1	1.3	1.4	1.7	2.0	2.5
600 $/kWp	2.5	2.7	3.0	3.3	3.8	4.3	5.0	6.0	7.5
1000 $/kWp	4.2	4.5	5.0	5.6	6.3	7.1	8.3	10.0	12.5
1400 $/kWp	5.8	6.4	7.0	7.8	8.8	10.0	11.7	14.0	17.5
1800 $/kWp	7.5	8.2	9.0	10.0	11.3	12.9	15.0	18.0	22.5
2200 $/kWp	9.2	10.0	11.0	12.2	13.8	15.7	18.3	22.0	27.5
2600 $/kWp	10.8	11.8	13.0	14.4	16.3	18.6	21.7	26.0	32.5
3000 $/kWp	12.5	13.6	15.0	16.7	18.8	21.4	25.0	30.0	37.5
3400 $/kWp	14.2	15.5	17.0	18.9	21.3	24.3	28.3	34.0	42.5
3800 $/kWp	15.8	17.3	19.0	21.1	23.8	27.1	31.7	38.0	47.5
4200 $/kWp	17.5	19.1	21.0	23.3	26.3	30.0	35.0	42.0	52.5
4600 $/kWp	19.2	20.9	23.0	25.6	28.8	32.9	38.3	46.0	57.5
5000 $/kWp	20.8	22.7	25.0	27.8	31.3	35.7	41.7	50.0	62.5

Problem: matching demand and supply



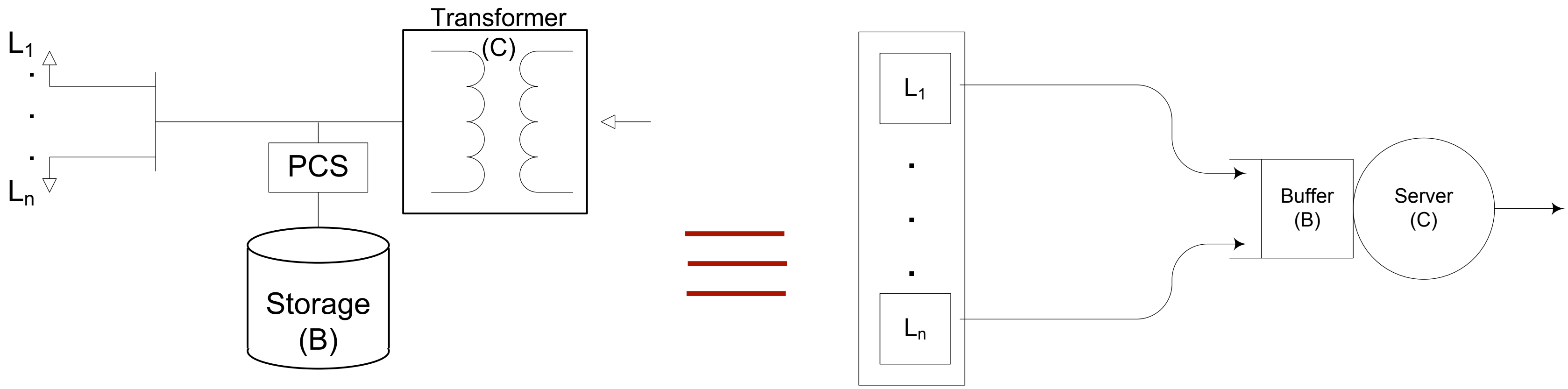
Barnhart *et al*, Proc. Energy and Environment, 6:2804, 2013

How to size with stochastic inputs?



Grid		Internet
Electrons	=	Bits
Load	=	Source
Transmission line	=	Communication link
Battery/energy store	=	Buffer
Demand response	=	Congestion control
Transmission network	=	Tier 1 ISP
Distribution network	=	Tier 2/3 ISP
Stochastic generator	=	Variable bit rate source

1. Equivalence theorem

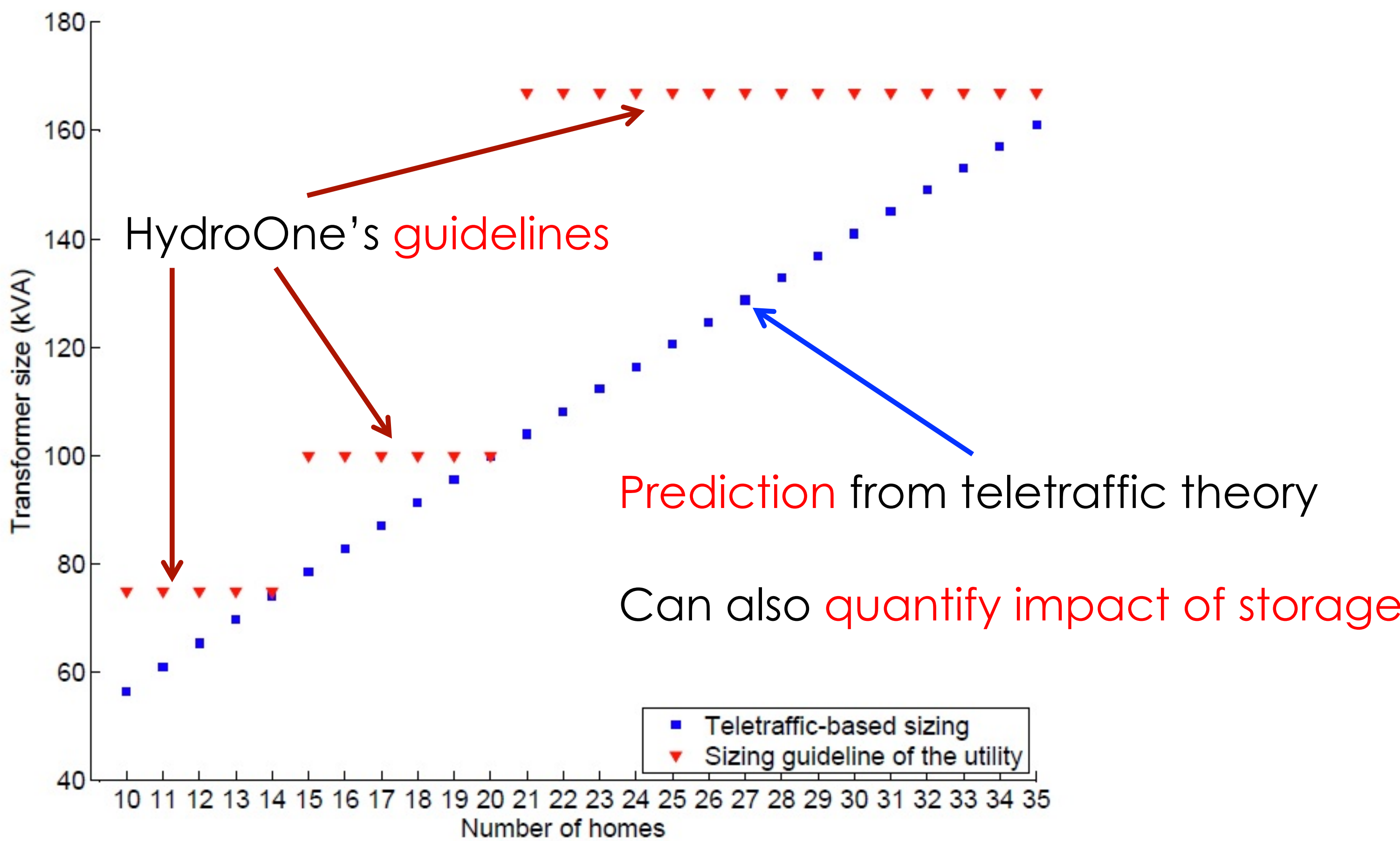


Every trajectory on the LHS has an equivalent on the RHS

- can use teletraffic theory to study transformer sizing

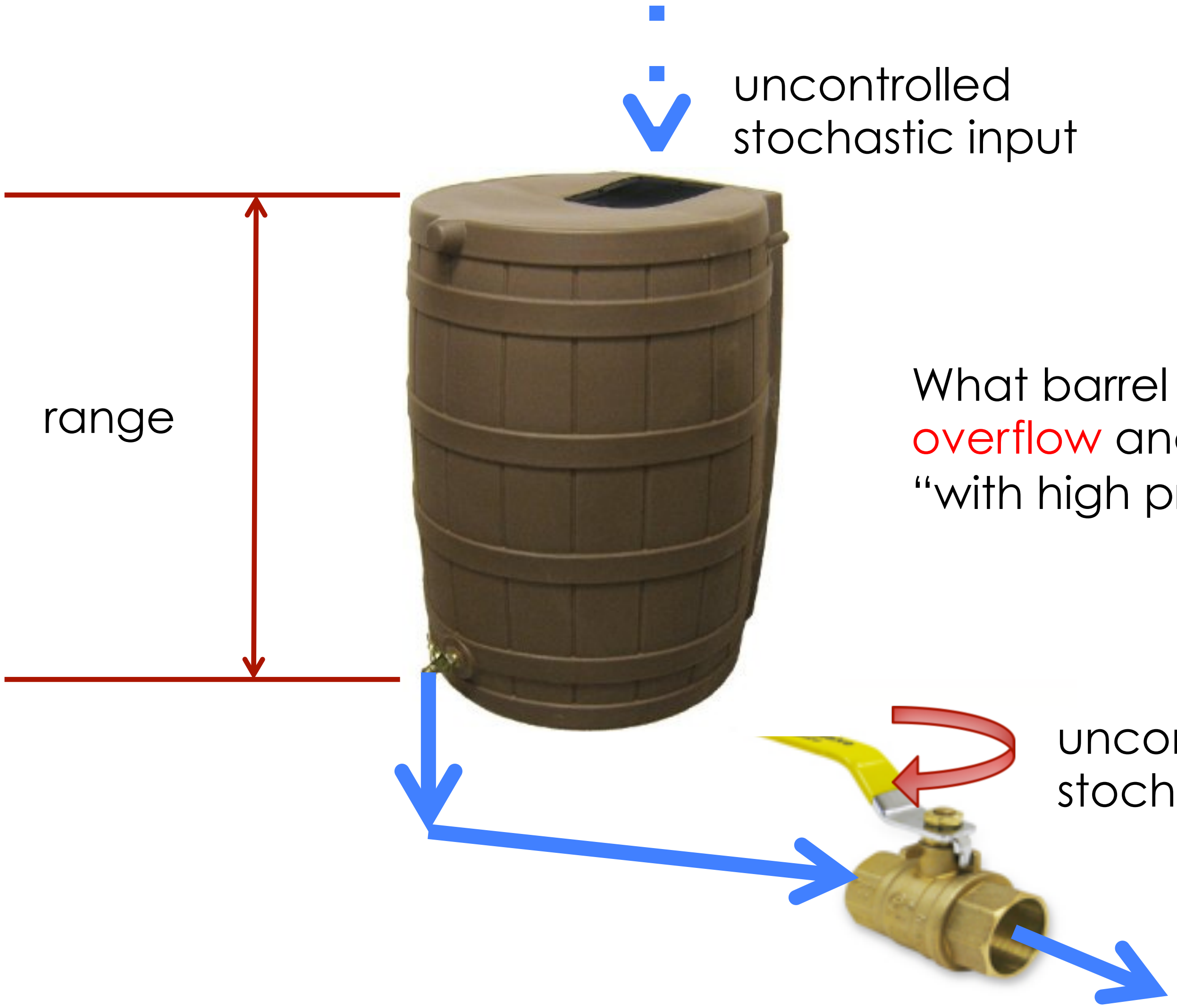
O. Ardakanian, S. Keshav, and C. Rosenberg. On the Use of Teletraffic Theory in Power Distribution Systems, e-Energy '12.

Guidelines for transformer sizing



O. Ardakanian, S. Keshav, and C. Rosenberg. On the Use of Teletraffic Theory in Power Distribution Systems, e-Energy '12.

2. How to model sources ?



What barrel size to avoid overflow and underflow "with high probability"?

Envelope idea

lower envelope ≤ Σ input ≤ upper envelope

Envelopes are computed from a dataset of trajectories

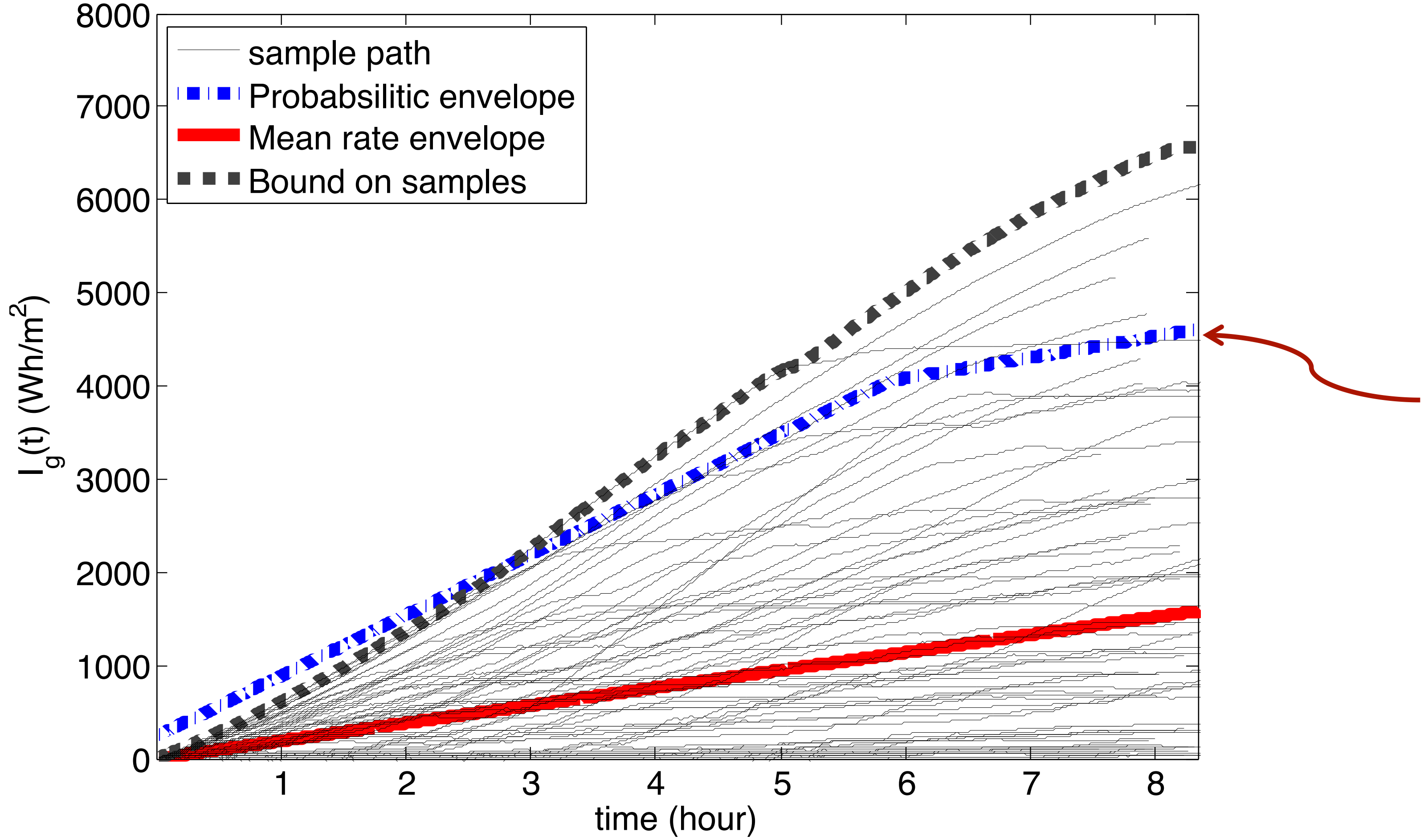
lower envelope ≤ Σ output ≤ upper envelope

Stochastic envelopes

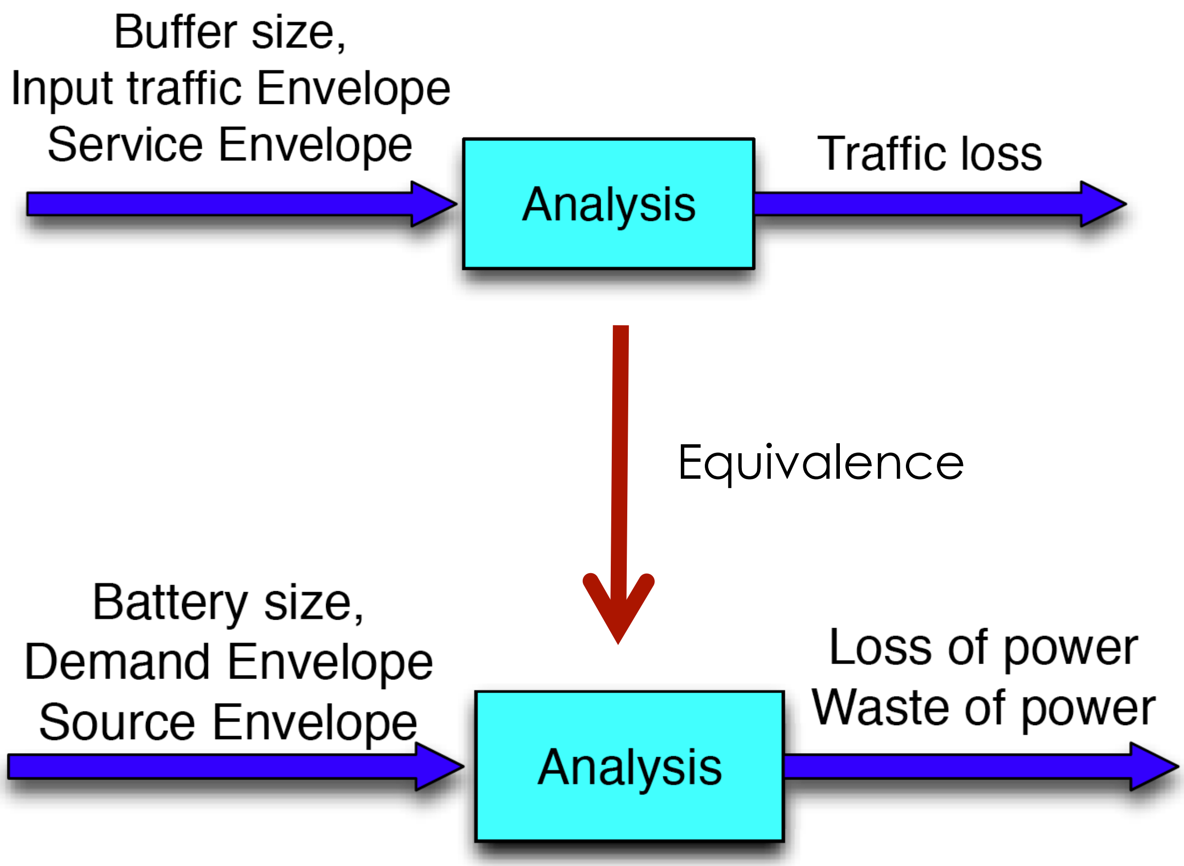
$P((\Sigma \text{ input - lower envelope}) > x) = ae^{-x}$

$P((\text{upper envelope} - \Sigma \text{ input}) > x) = be^{-x}$

Solar stochastic sample path envelopes

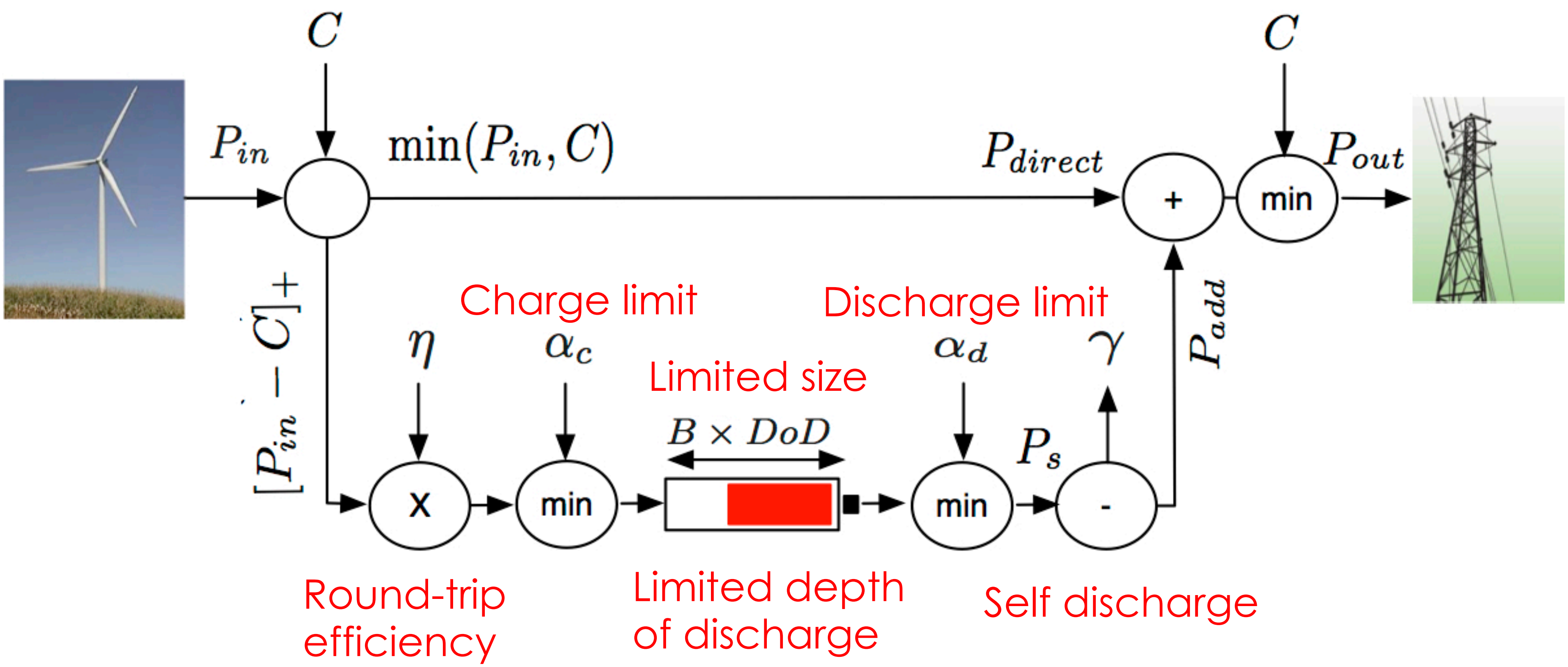


Stochastic network calculus



Wang, Kai, et al. "A stochastic power network calculus for integrating renewable energy sources into the power grid." *Selected Areas in Communications, IEEE Journal on* 30.6 (2012): 1037-1048.

3. Storage imperfections



Observation

$$b(t) = \min\Big(\underbrace{B \times DoD}_{\text{modified size}},\ \Big[\underbrace{\min\left([P_{in}(t) - C]_+, \alpha_c\right)\eta}_{\text{modified arrival process}} - \underbrace{\min([C - P_{in}(t)]_+, \alpha_d) - \gamma}_{\text{modified departure process}} + b(t-1)\Big]_+\Big)$$

modified
size

modified
arrival process

modified
departure process

⇒ we can convert results obtained for non-ideal batteries to results for RAM-based buffers!

Analytic results

- Minimizing storage size to smooth solar/wind sources
- Optimal participation of a solar or wind farm in day-ahead energy markets
- Optimal operation of diesel generators to deal with power cuts in developing countries
- Optimal allocation of capital to solar and storage
- Modeling of hybrid (SCAP + Li-Ion) storage systems

Joint work with Y. Ghiassi-Farrokhfal, S. Singla, F. Kazhmiaka, M.-B. Adjaho, and C. Rosenberg

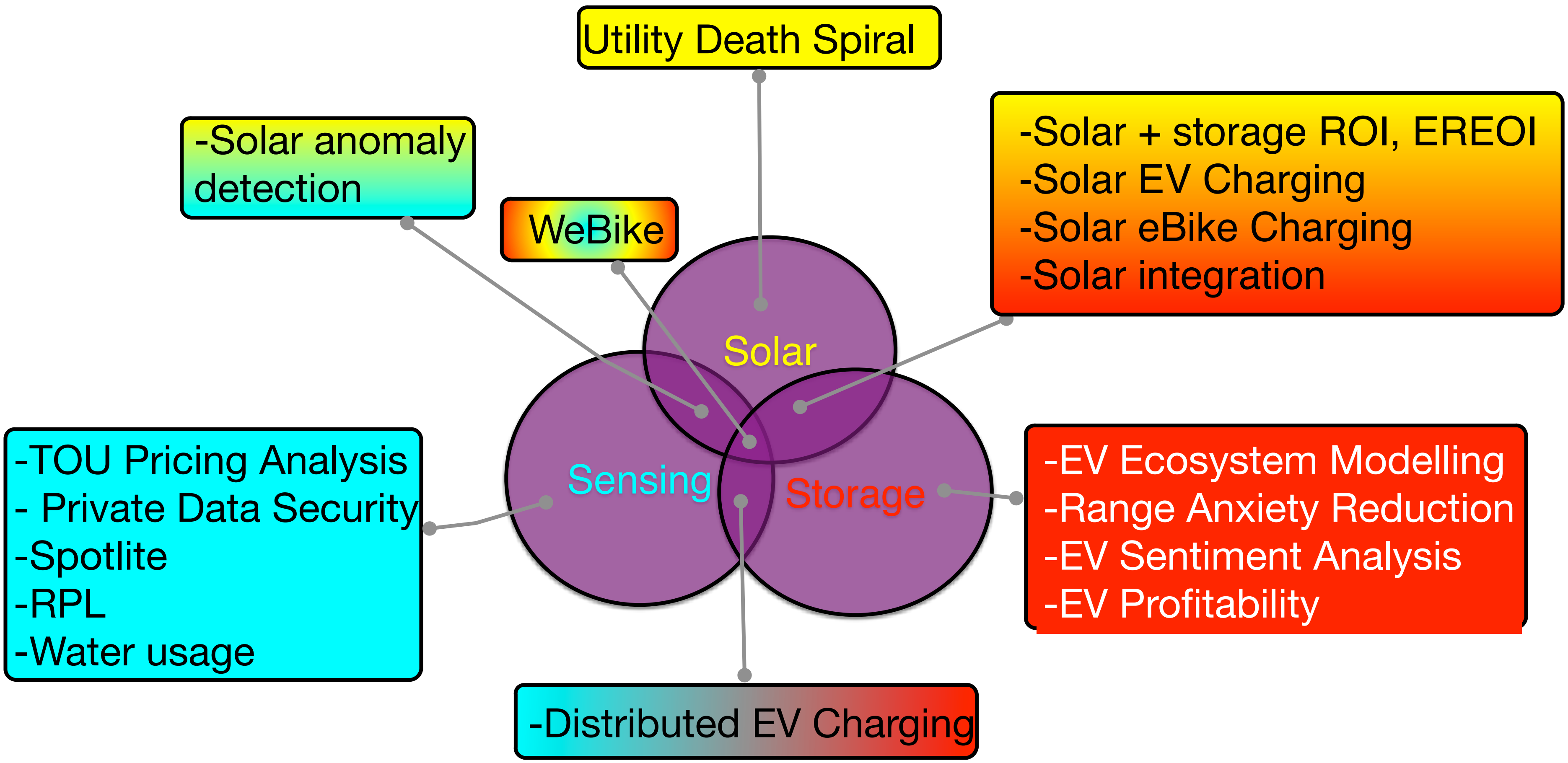
ISS4E

To use information systems and science to

- increase the efficiency
- reduce the carbon footprint

of energy systems

SSS: Solar, Storage, Sensing



Conclusions

- Renewable energy sources are inherently stochastic
- Can model using fluid flow models and stochastic network calculus
- Early results are encouraging

ISS4E@UW

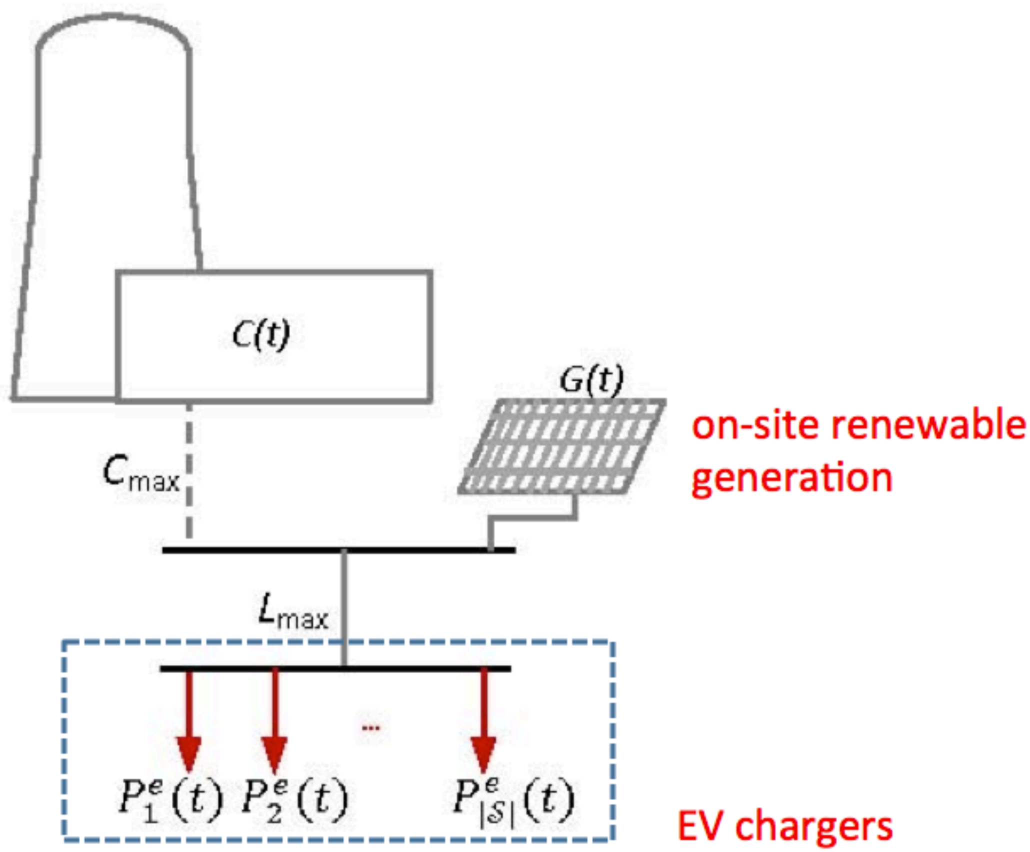
- We are always interested in collaborations:
  - ISS4E mailing list
  - ISS4E seminar series starting October 2013

http://iss4e.ca

Solar + Storage: Solar EV Charging

- Base case (no solar): try meeting all charging deadlines
  - If infeasible; perform fair allocation

- Integrate solar to reduce emissions while ensuring same (or greater) utility



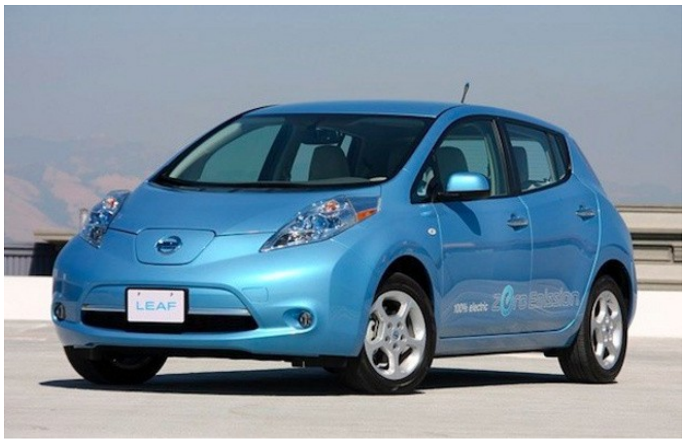
Three inflection points

- Solar
- Storage
- Sensing (and control)

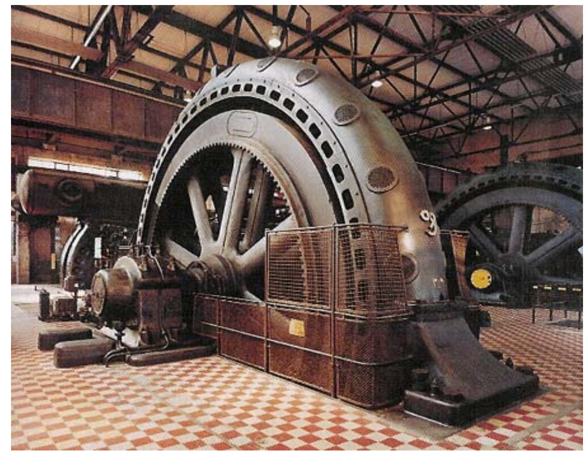
Storage research, investment growth

Global investment to reach $122 Billion by 2021 – Pike Research

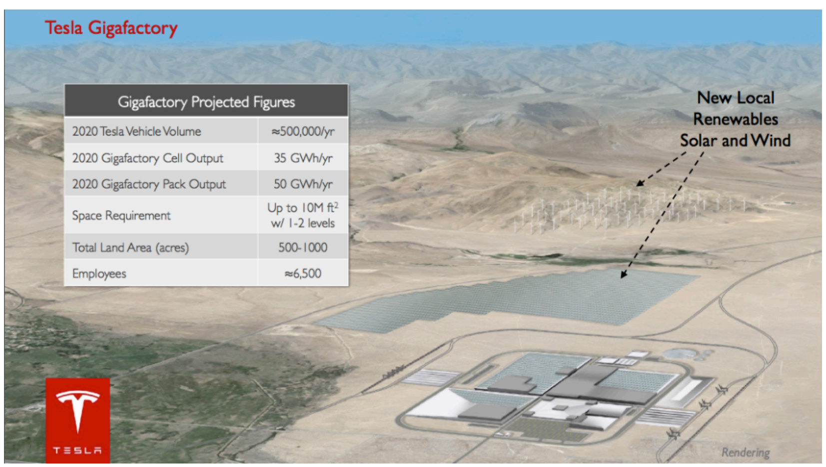
Largest change: EVs



Some grid storage

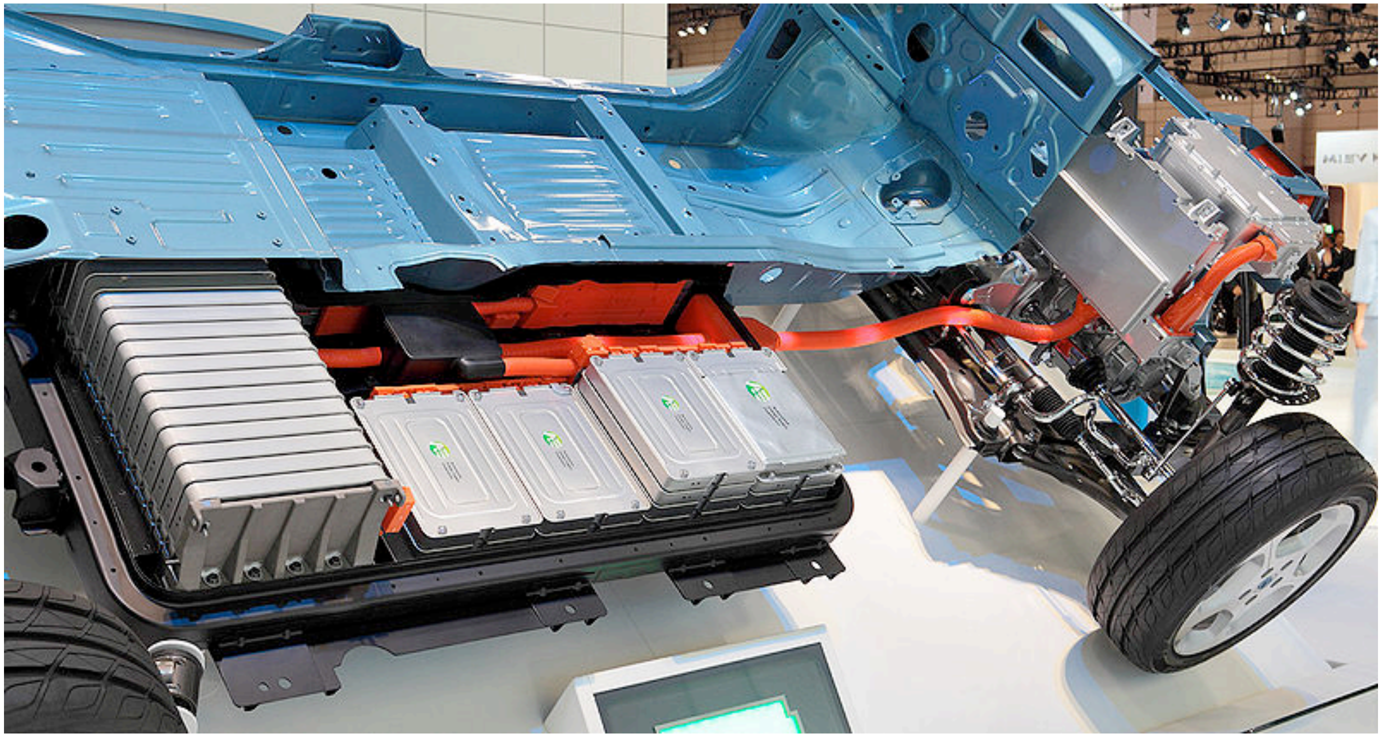


LiON Declining. $600 down to <$200



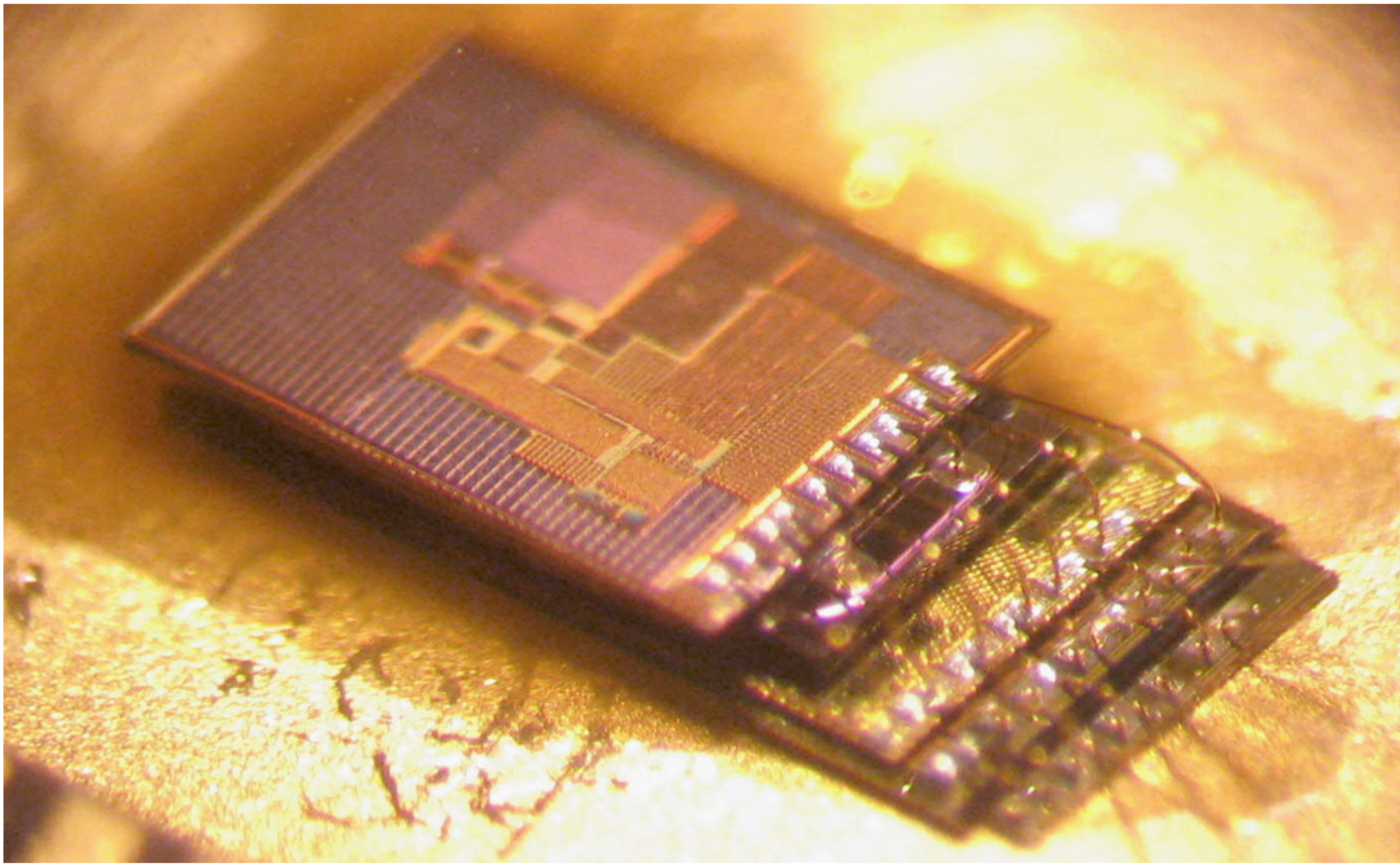
4. Electric vehicles

- Spur research on lower-cost storage
- Huge consumers of electricity



Nissan Leaf chassis

5. Pervasive sensing

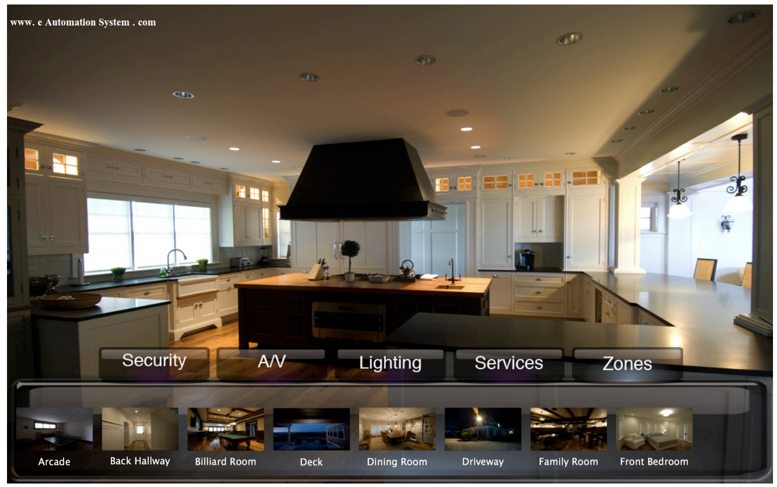


Michigan Micro Mote

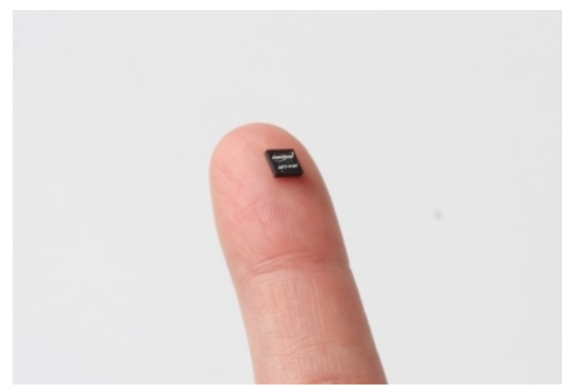
Sensing & Control

Grid

Home



Pervasive



Michigan Micro Mote

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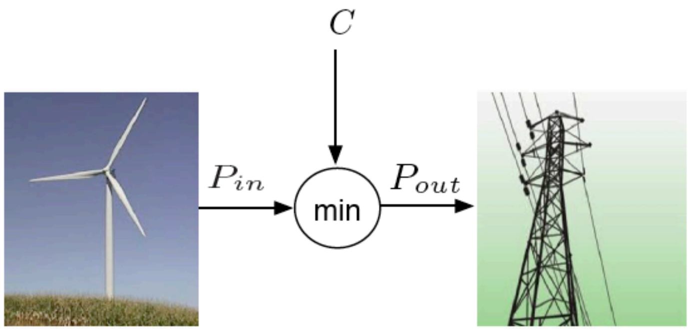
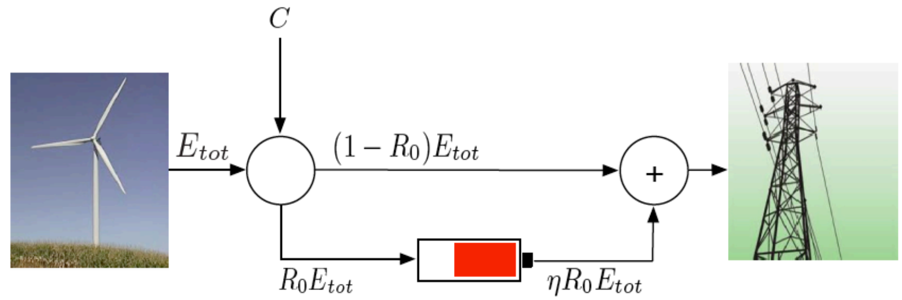
Solar + Storage:
ROI, EROEI of Solar Systems w/ Storage





Simple curtailment:

- More energy waste
- No investment on storage

Using energy storage systems:

- Less energy waste
- Additional energy to produce energy storage systems

-Advanced modeling of stochastic inputs, comprehensive battery model

hence slow progress:

-Demand response: only time of use pricing

-Grid storage: tiny

-Smart buildings and homes: demo stage

-Microgrids: rare

-Electric vehicles: early mainstream

-Security and privacy: mostly missing

Reflections on the research area

Energy research

Pros

- Rapidly growing research area
- Many open problems
- Industry interest and support
- Motivated students
- Potential for impact

Cons

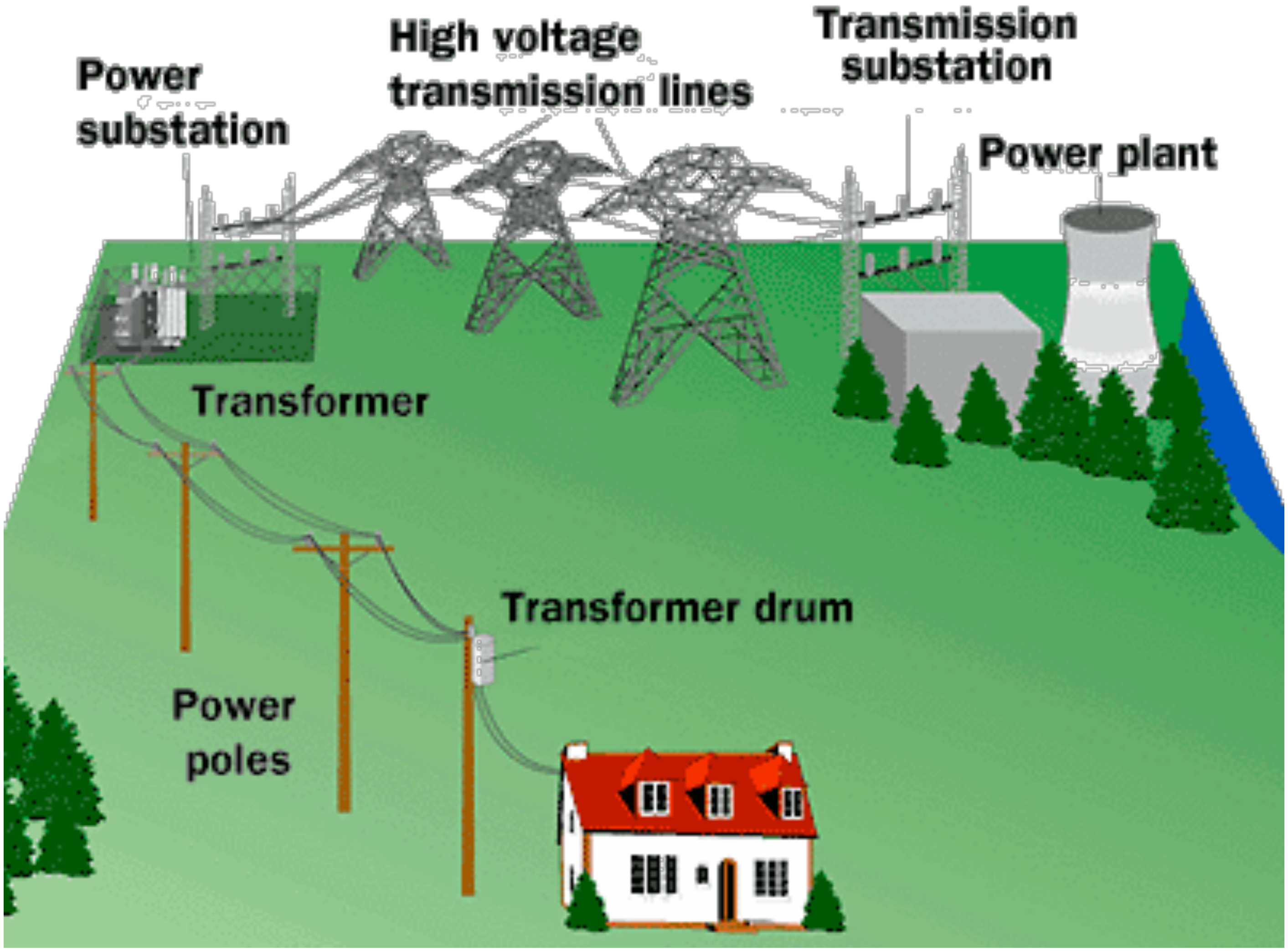
- Requires learning new concepts and ideas
- Entrenched interests
- Difficult to obtain data
- Field trials nearly impossible

Today's Electrical Grid

3 components

- Generation
- Transmission
- Distribution

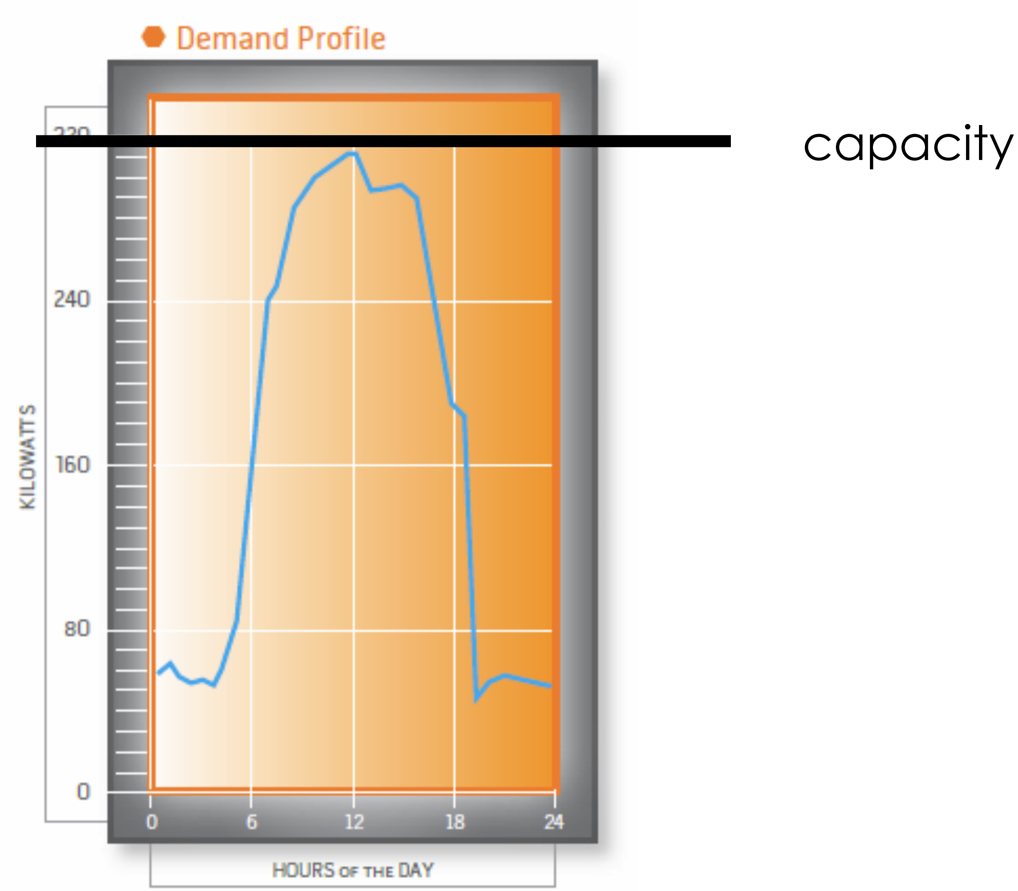
Current grid	"Smart" grid
Centralized	Decentralized
Little to no storage	Storage rich
High carbon	Renewables/low carbon
Poorly measured	Sensing rich
Poorly controlled	Control rich
Ossified	Flexible
Inefficient	Energy frugal



Howstuffworks.com

Grid characteristics

1. Overprovisioned by design



2. Inefficient

5% better efficiency of US grid

= zero emission from 53 million cars

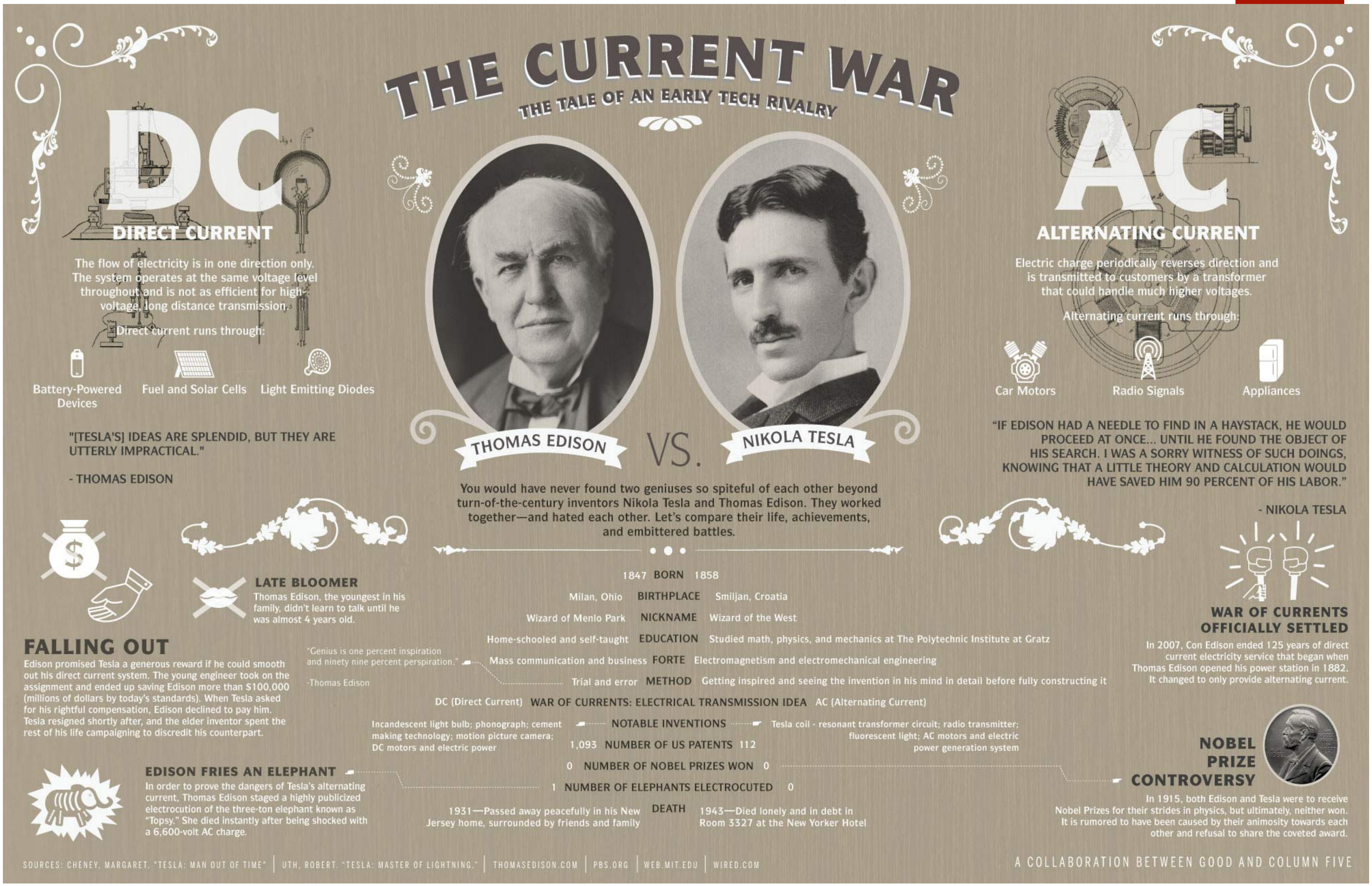
http://www.oe.energy.gov/

4. Uneven

	TWh generated	Daily W/capita (2012 est.)
China	4,938	395
US	4,256	1402

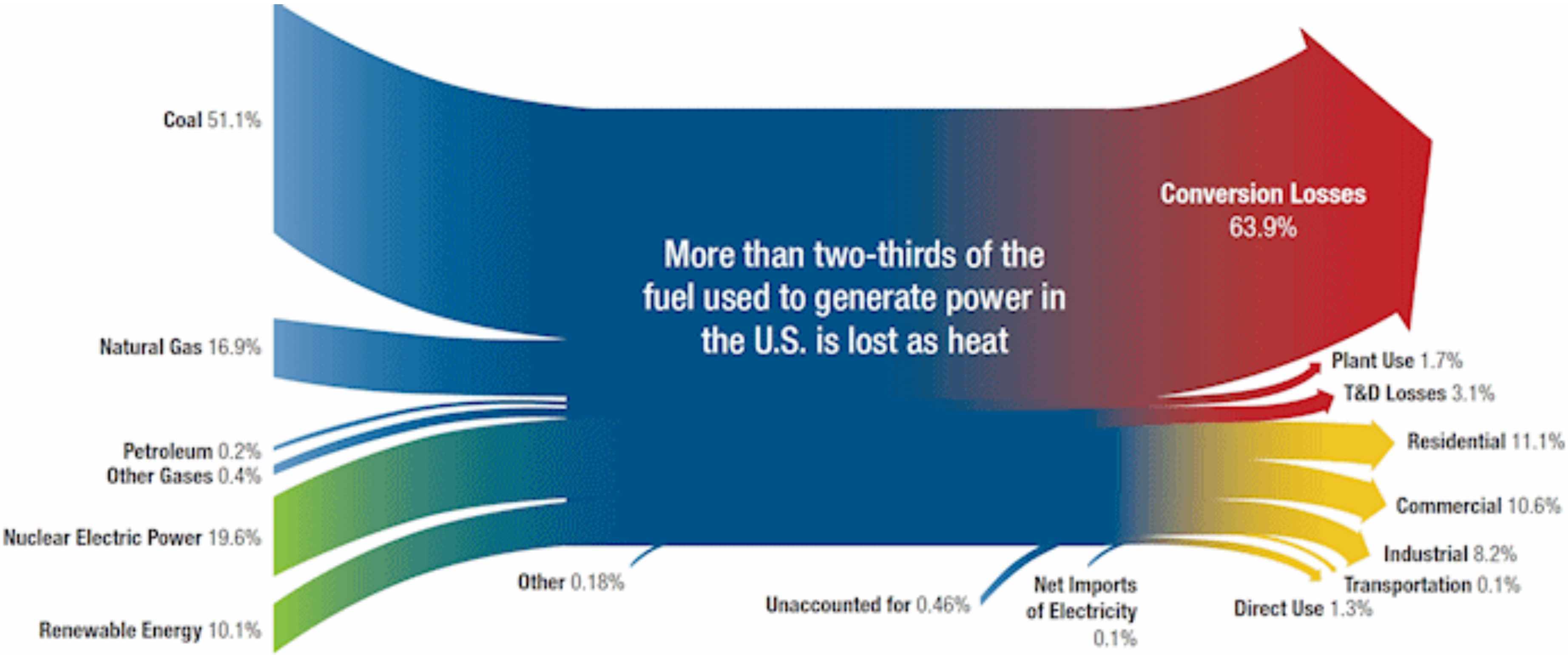
Wikipedia

…is old



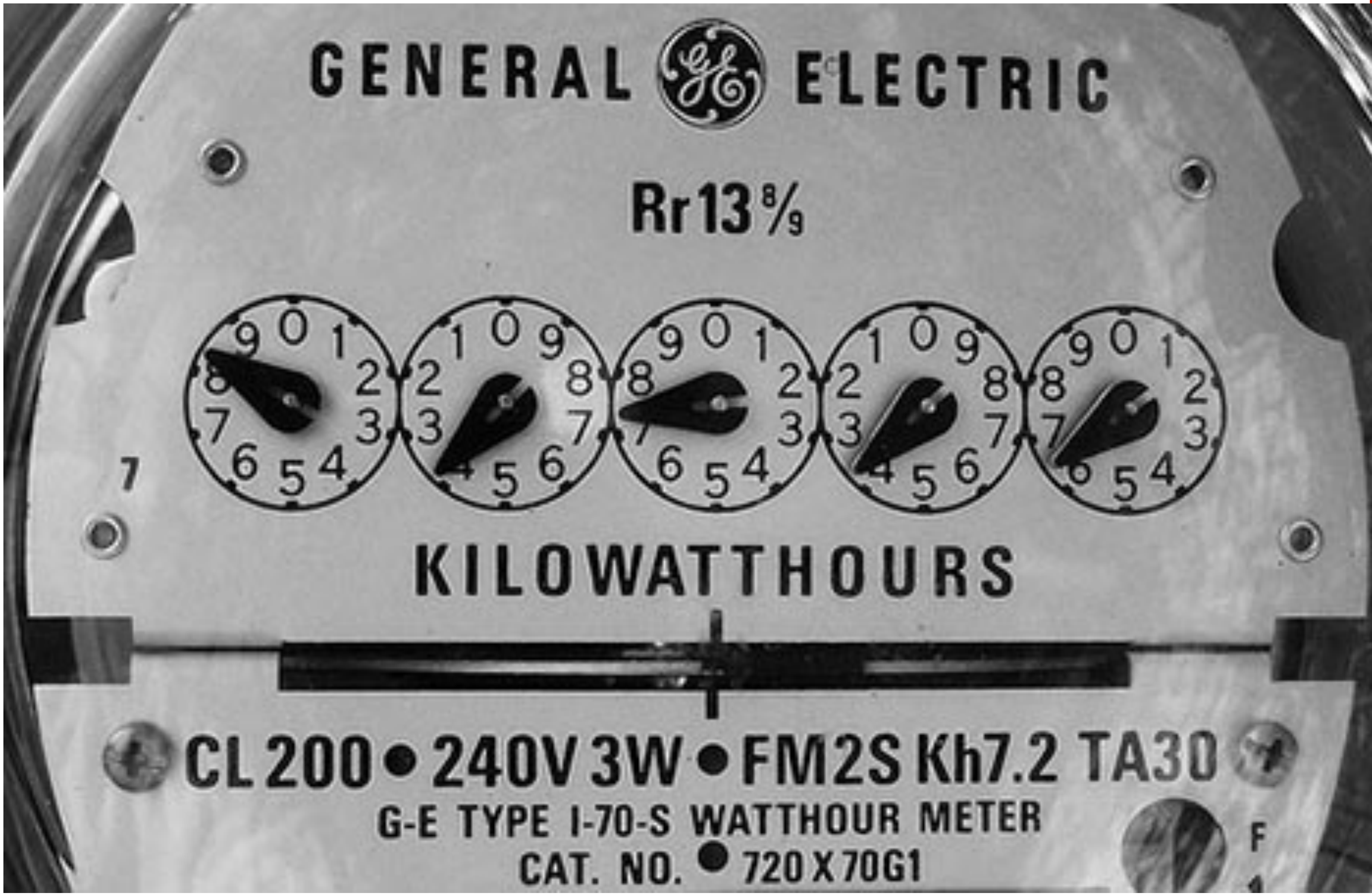
THE CURRENT WAR
THE TALE OF AN EARLY TECH RIVALRY
DC
DIRECT CURRENT
The flow of electricity is in one direction only. The system operates at the same voltage level throughout and is not as efficient for high-voltage, long distance transmission.
Direct current runs through:
Battery-Powered Devices
Fuel and Solar Cells
Light Emitting Diodes
"[TESLA'S] IDEAS ARE SPLENDID, BUT THEY ARE UTTERLY IMPRACTICAL."
- THOMAS EDISON
AC
ALTERNATING CURRENT
Electric charge periodically reverses direction and is transmitted to customers by a transformer that could handle much higher voltages.
Alternating current runs through:
Car Motors
Radio Signals
Appliances
"IF EDISON HAD A NEEDLE TO FIND IN A HAYSTACK, HE WOULD PROCEED AT ONCE... UNTIL HE FOUND THE OBJECT OF HIS SEARCH. I WAS A SORRY WITNESS OF SUCH DOINGS, KNOWING THAT A LITTLE THEORY AND CALCULATION WOULD HAVE SAVED HIM 90 PERCENT OF HIS LABOR."
- NIKOLA TESLA
THOMAS EDISON
VS.
NIKOLA TESLA
You would have never found two geniuses so spiteful of each other beyond turn-of-the-century inventors Nikola Tesla and Thomas Edison. They worked together—and hated each other. Let's compare their life, achievements, and embittered battles.
LATE BLOOMER
Thomas Edison, the youngest in his family, didn't learn to talk until he was almost 4 years old.
FALLING OUT
Edison promised Tesla a generous reward if he could smooth out his direct current system. The young engineer took on the assignment and ended up saving Edison more than $100,000 (millions of dollars by today's standards). When Tesla asked for his rightful compensation, Edison declined to pay him. Tesla resigned shortly after, and the elder inventor spent the rest of his life campaigning to discredit his counterpart.
"Genius is one percent inspiration and ninety nine percent perspiration."
-Thomas Edison
1847 BORN 1858
Milan, Ohio BIRTHPLACE Smiljan, Croatia
Wizard of Menlo Park NICKNAME Wizard of the West
Home-schooled and self-taught EDUCATION Studied math, physics, and mechanics at The Polytechnic Institute at Gratz
Mass communication and business FORTE Electromagnetism and electromechanical engineering
Trial and error METHOD Getting inspired and seeing the invention in his mind in detail before fully constructing it
DC (Direct Current) WAR OF CURRENTS: ELECTRICAL TRANSMISSION IDEA AC (Alternating Current)
Incandescent light bulb; phonograph; cement making technology; motion picture camera; DC motors and electric power
NOTABLE INVENTIONS
Tesla coil - resonant transformer circuit; radio transmitter; fluorescent light; AC motors and electric power generation system
1,093 NUMBER OF US PATENTS 112
0 NUMBER OF NOBEL PRIZES WON 0
1 NUMBER OF ELEPHANTS ELECTROCUTED 0
1931—Passed away peacefully in his New Jersey home, surrounded by friends and family
DEATH
1943—Died lonely and in debt in Room 3327 at the New Yorker Hotel
EDISON FRIES AN ELEPHANT
In order to prove the dangers of Tesla's alternating current, Thomas Edison staged a highly publicized electrocution of the three-ton elephant known as "Topsy." She died instantly after being shocked with a 6,600-volt AC charge.
WAR OF CURRENTS OFFICIALLY SETTLED
In 2007, Con Edison ended 125 years of direct current electricity service that began when Thomas Edison opened his power station in 1882. It changed to only provide alternating current.
NOBEL PRIZE CONTROVERSY
In 1915, both Edison and Tesla were to receive Nobel Prizes for their strides in physics, but ultimately, neither won. It is rumored to have been caused by their animosity towards each other and refusal to share the coveted award.
SOURCES: CHENEY, MARGARET. "TESLA: MAN OUT OF TIME" | UTH, ROBERT. "TESLA: MASTER OF LIGHTNING." | THOMASEDISON.COM | PBS.ORG | WEB.MIT.EDU | WIRED.COM
A COLLABORATION BETWEEN GOOD AND COLUMN FIVE

…inefficient

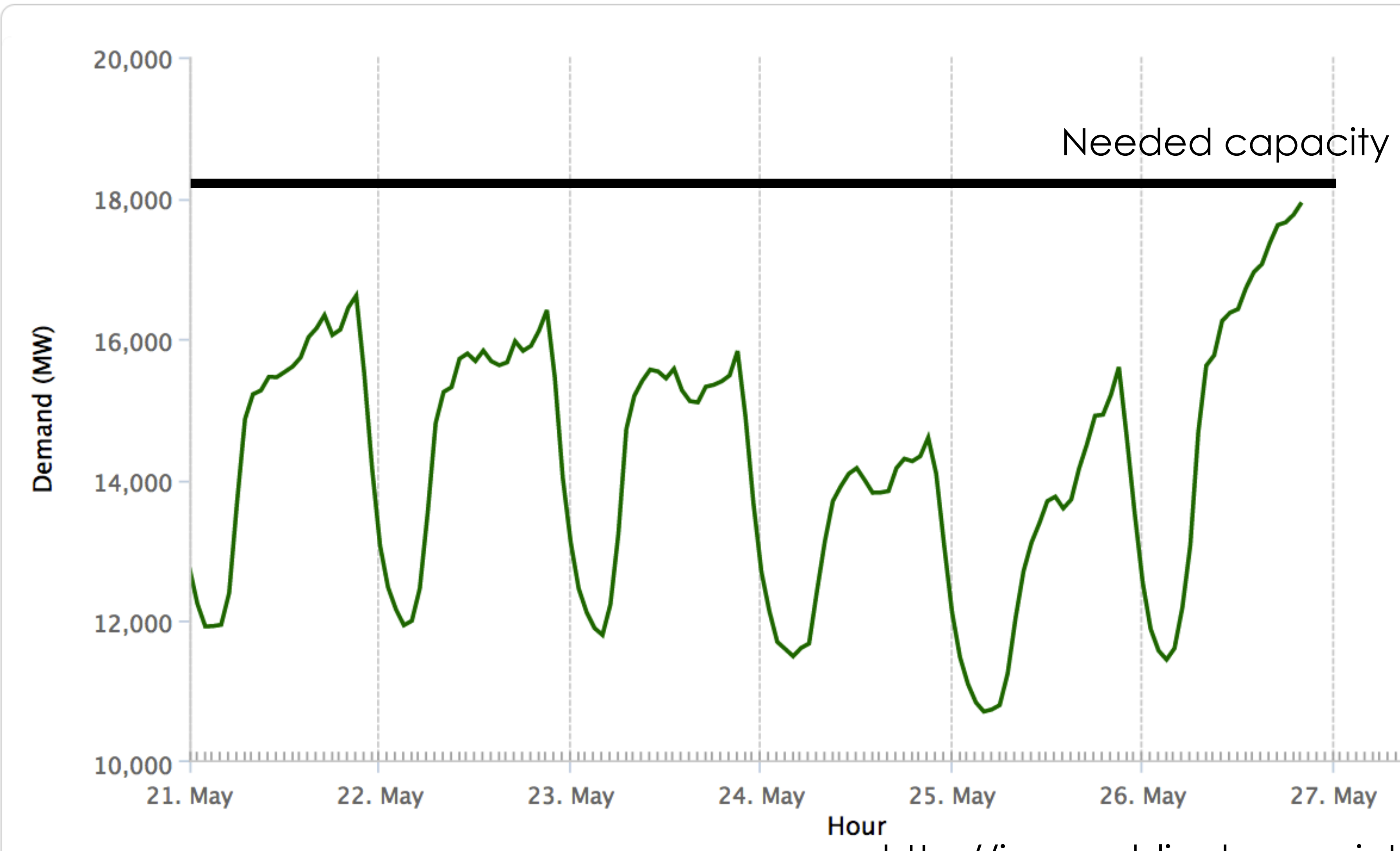


US DOE: http://www.southeastchptap.org/cleanenergy/chp/

…poorly measured



…without storage (mostly)



http://ieso-public.sharepoint.com

…but Consumers & Utilities lack incentives

Savings of 10%: $5-10/month

Utilities make $$ regardless