Smart Grid Forum

S. Keshav

November 12, 2014

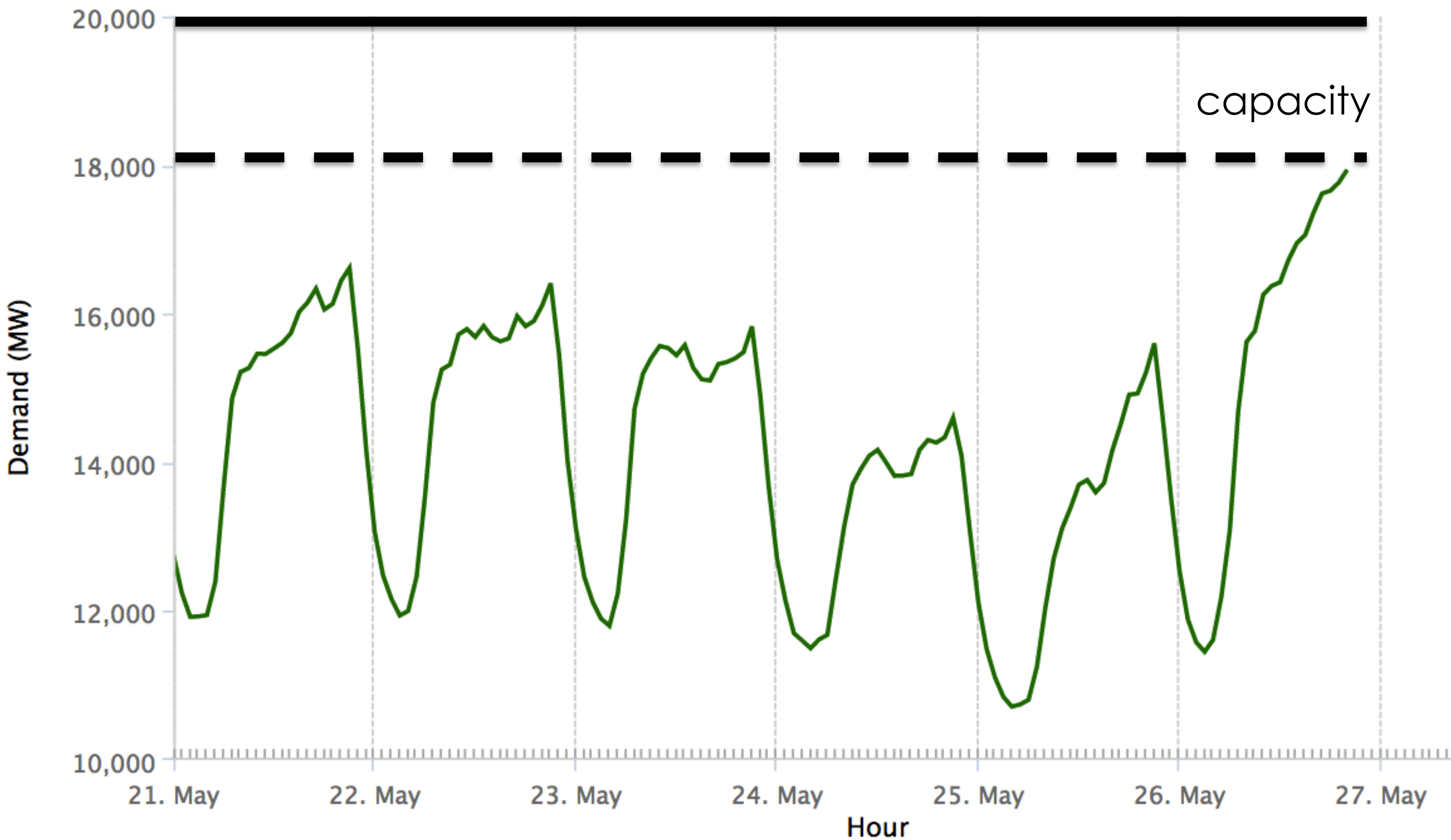
Agenda

- Overview
- Deep(er) dives
  - Energy-optimal routing in RPL
  - Smart home data management
  - Telemetry for e-bikes
  - Personal thermal comfort

Today’s Energy Infrastructure

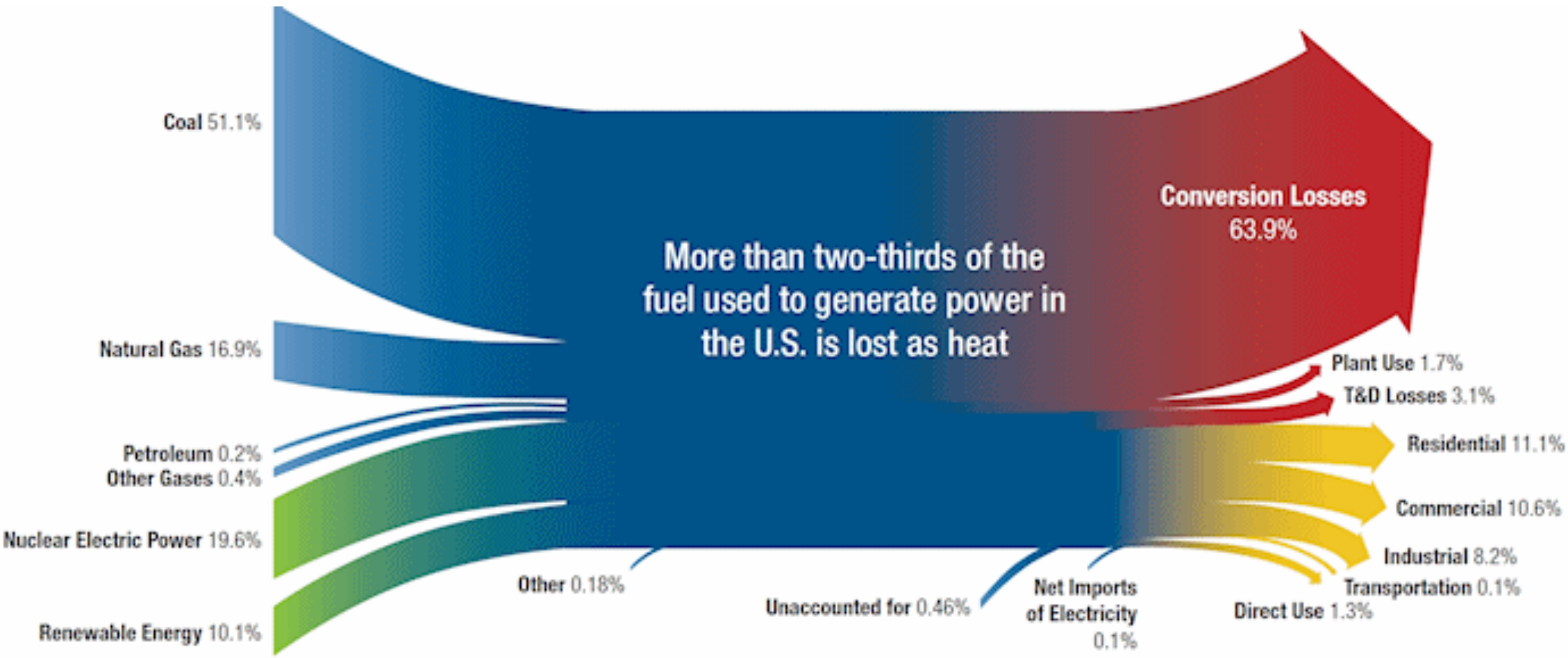
Mostly dirty…

Overprovisioned by design



http://ieso-public.sharepoint.com/

Inefficient



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

Wasteful…

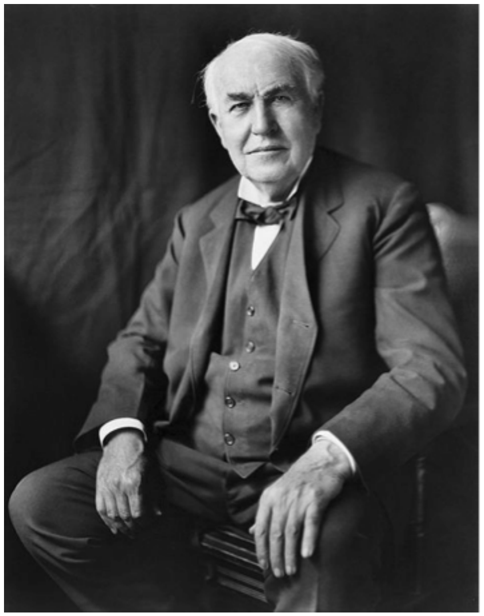

TIMES SQUARE
MOTOWN
CHRYSLER 300 MOTOWN EDITION
THE CROWD GOES WILD!
MAMMA MIA!

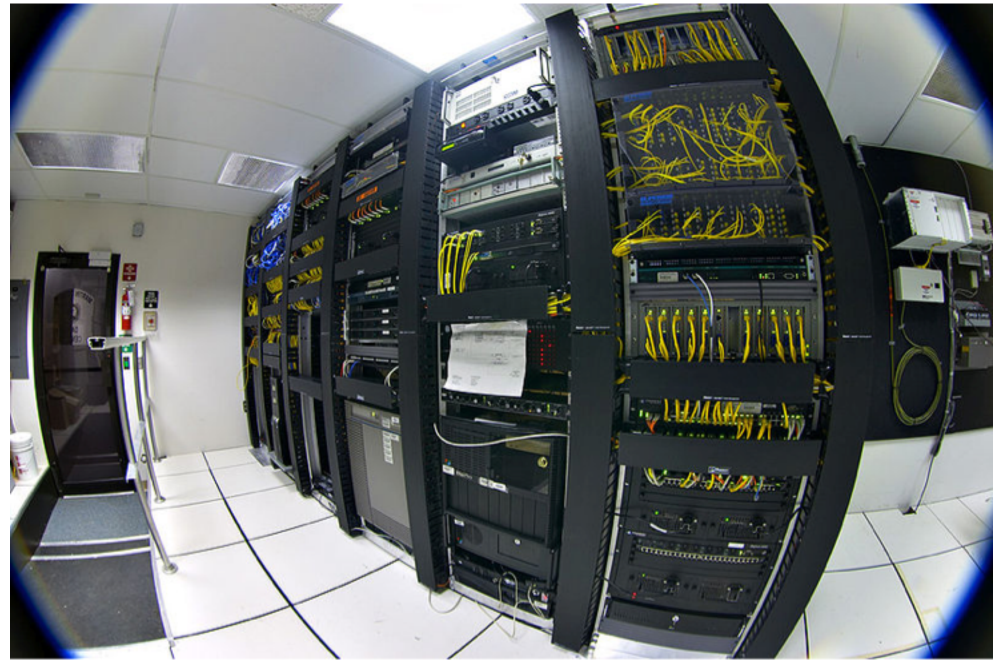

北の家族
アコム
プロミス

5% better efficiency of US grid

= zero emission from 53 million cars

Aging

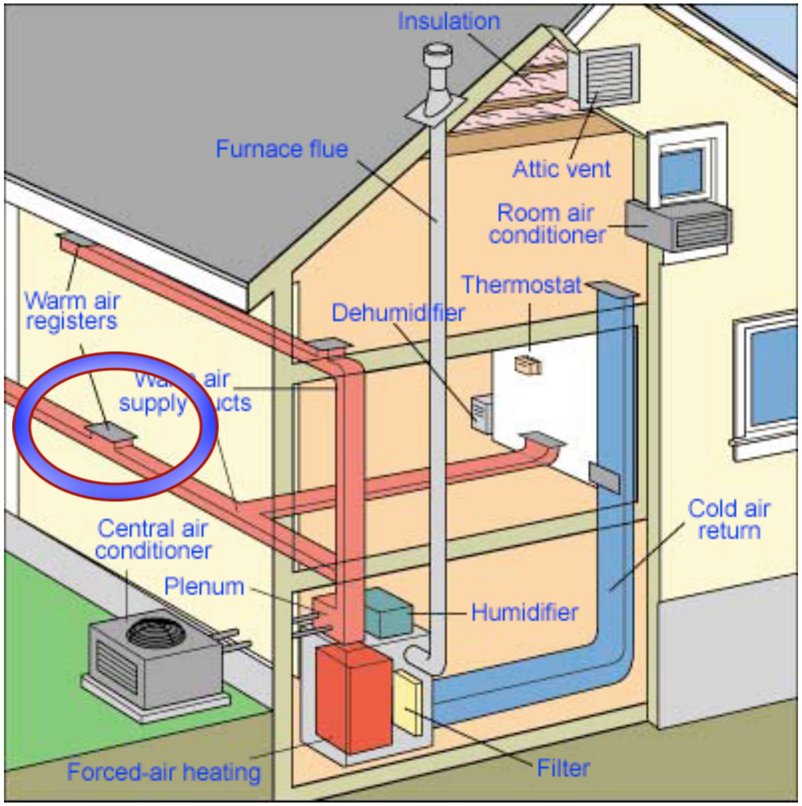




Post-war infrastructure is reaching EOL

Poorly measured

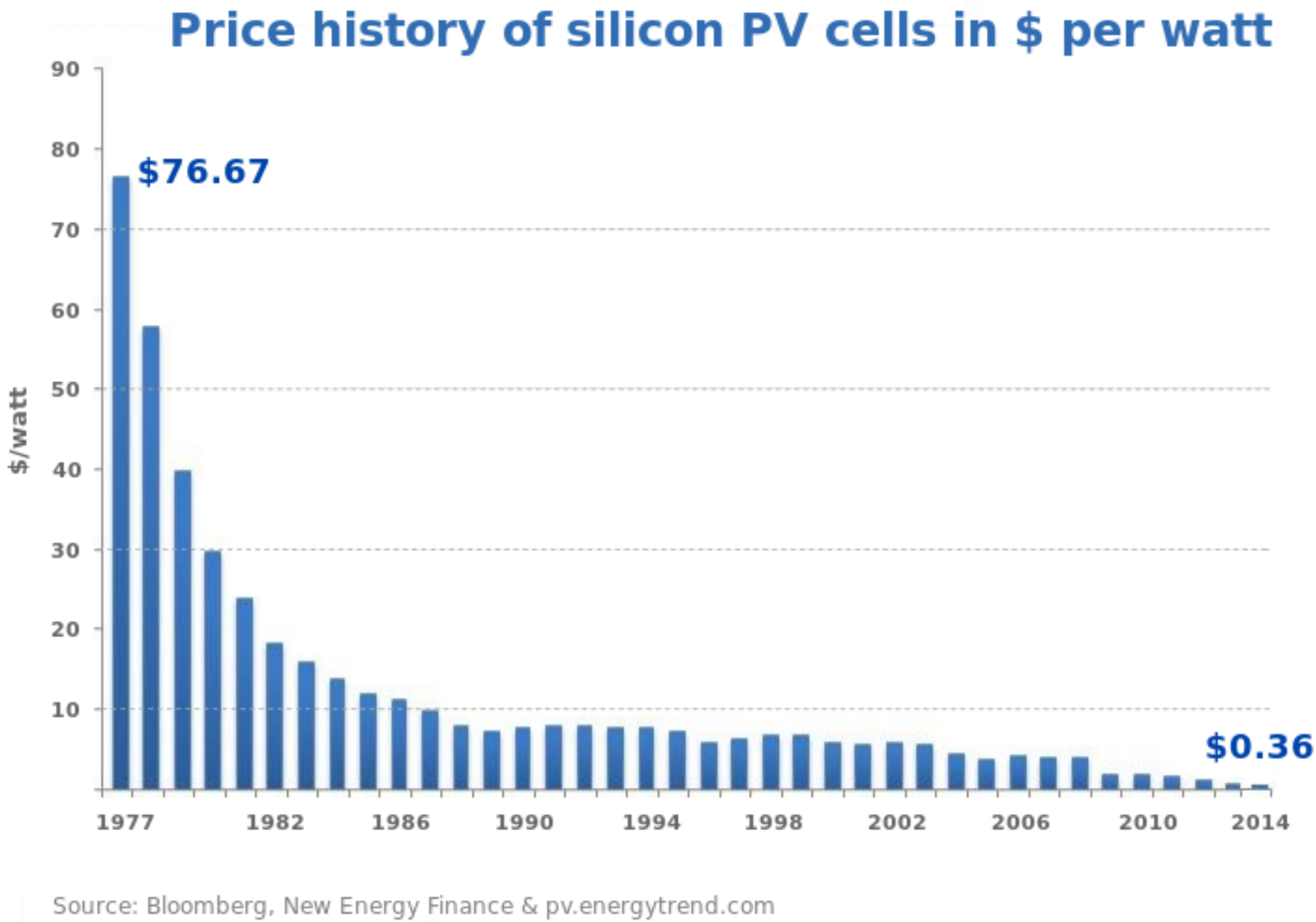
Poorly controlled



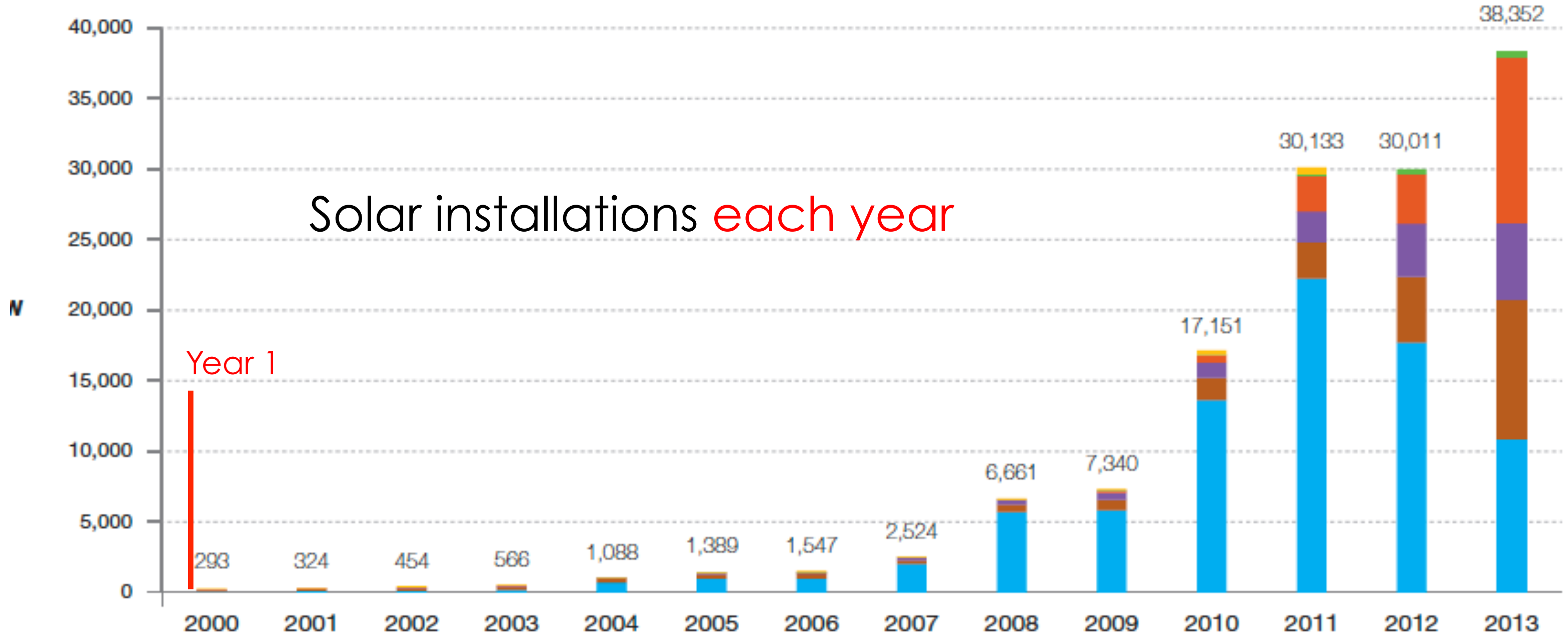
Times are changing…

Three technology inflection points

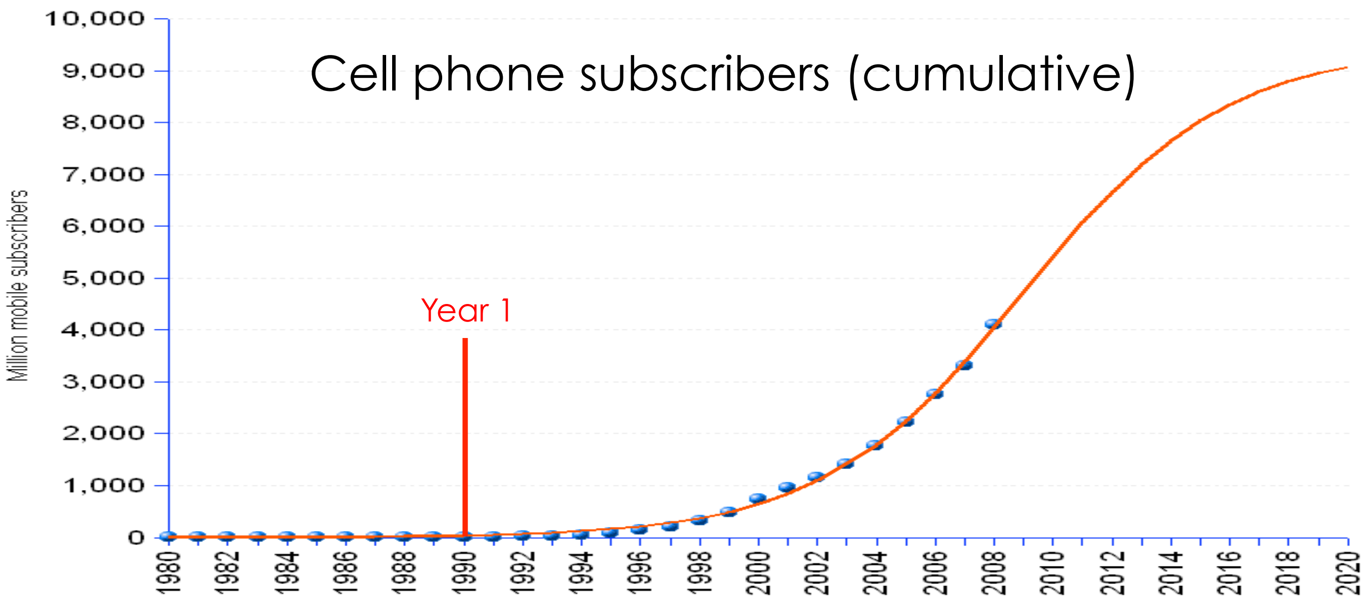
- Solar and wind renewable generation
- Storage and EVs
- Pervasive sensing and control



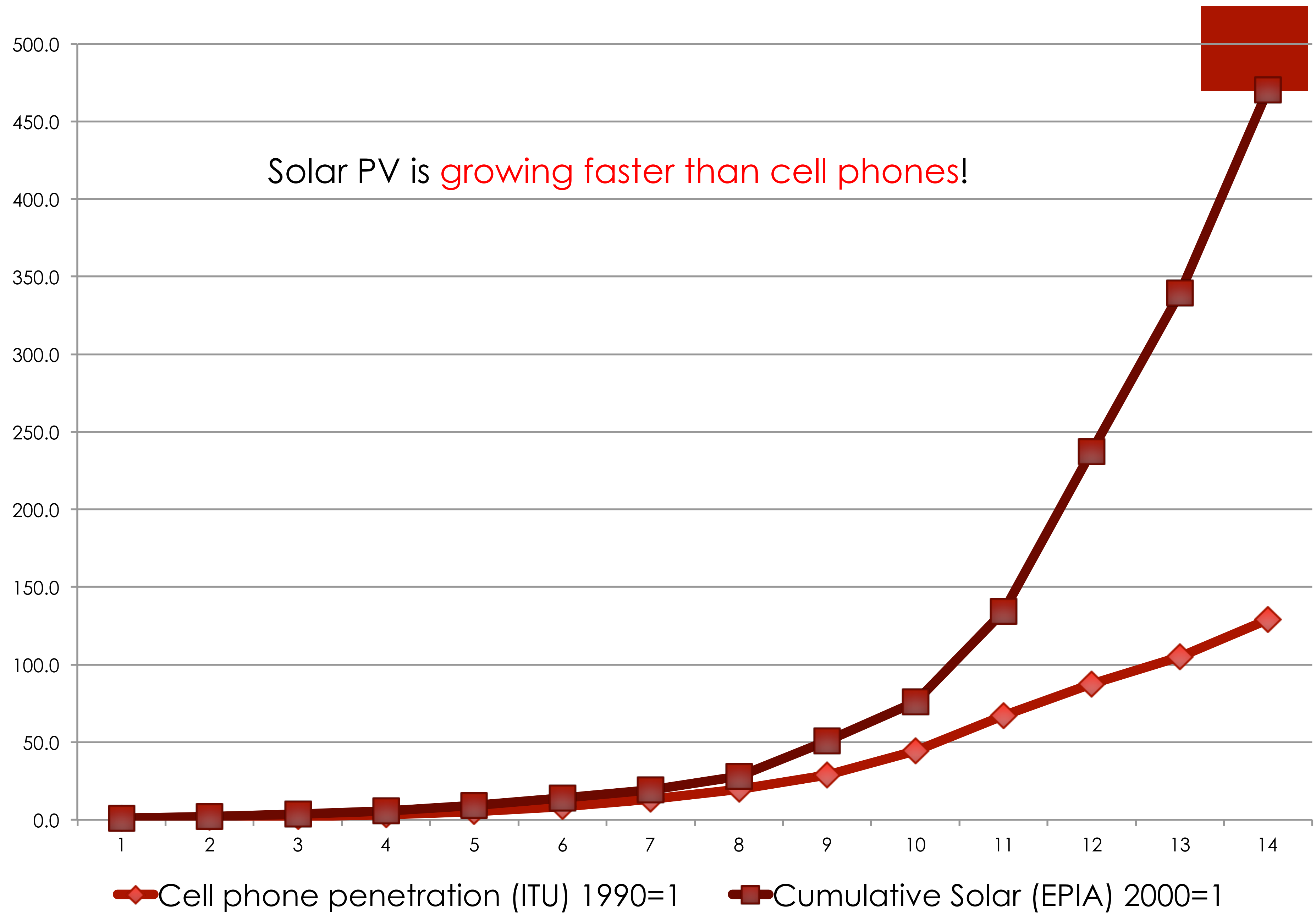
Price history of silicon PV cells in $ per watt
$/watt
90
80
70
60
50
40
30
20
10
$76.67
$0.36
1977
1982
1986
1990
1994
1998
2002
2006
2010
2014
Source: Bloomberg, New Energy Finance & pv.energytrend.com



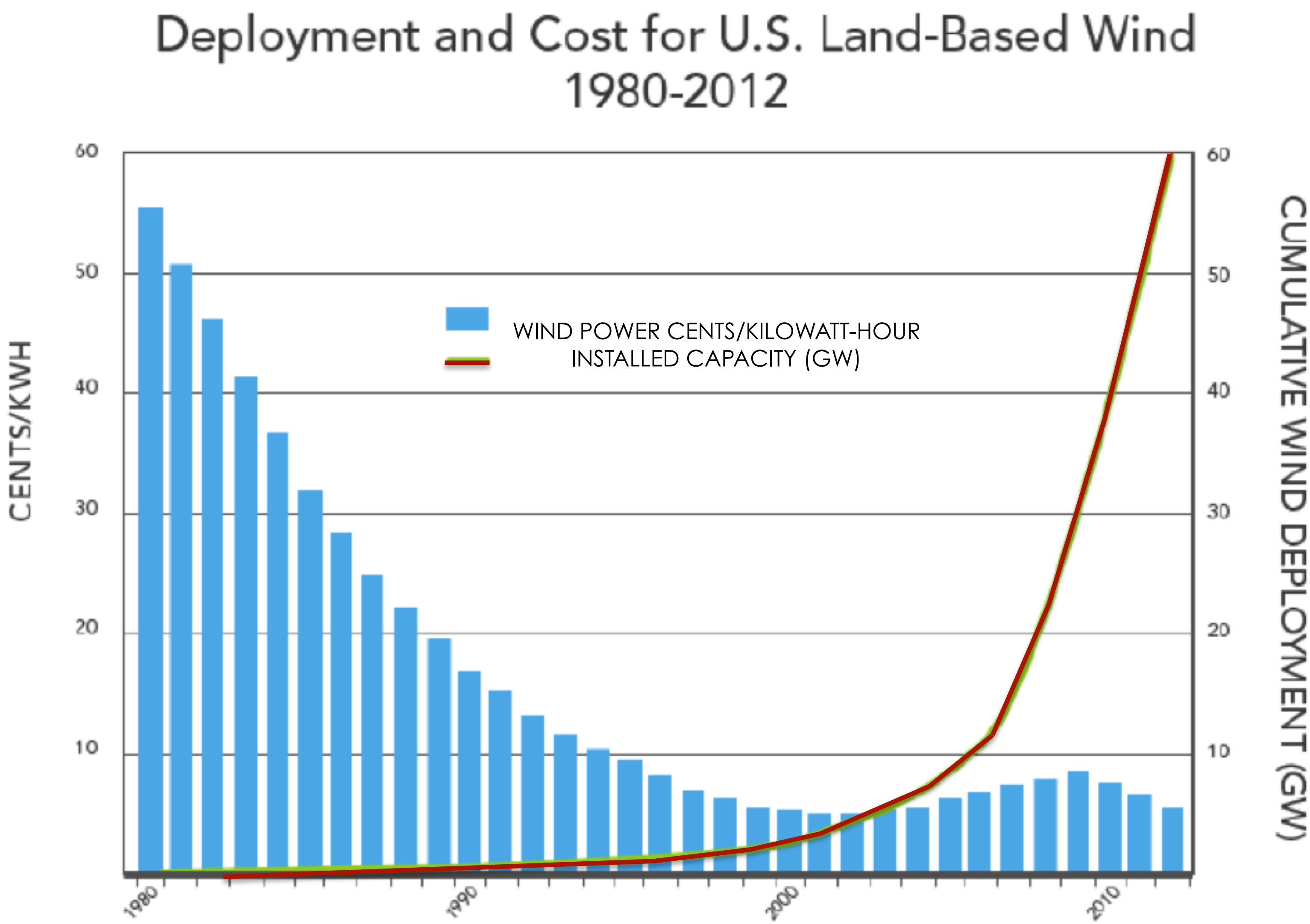
http://www.epia.org/fileadmin/user_upload/Publications/EPIA_Global_Market_Outlook_for_Photovoltaics_2014-2018_-_Medium_Res.pdf



http://stats.areppim.com/stats/stats_mobile.htm



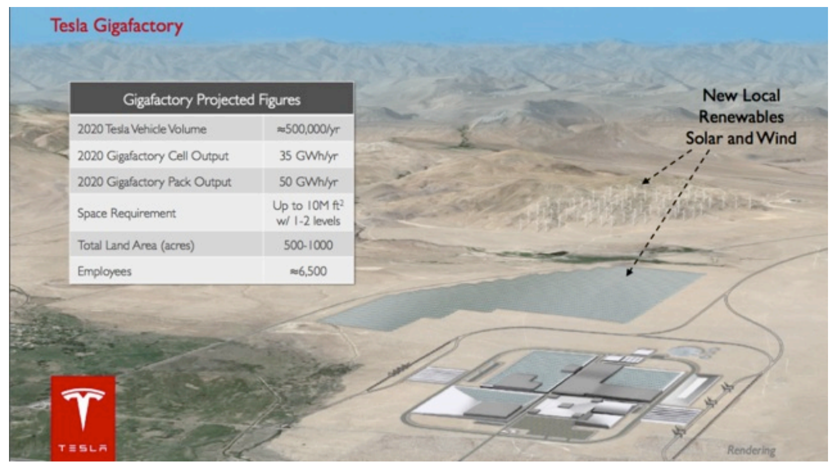
Solar PV is growing faster than cell phones!
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Cell phone penetration (ITU) 1990=1
Cumulative Solar (EPIA) 2000=1



"Revolution Now," US DOE Sept. 17. 2013

Storage

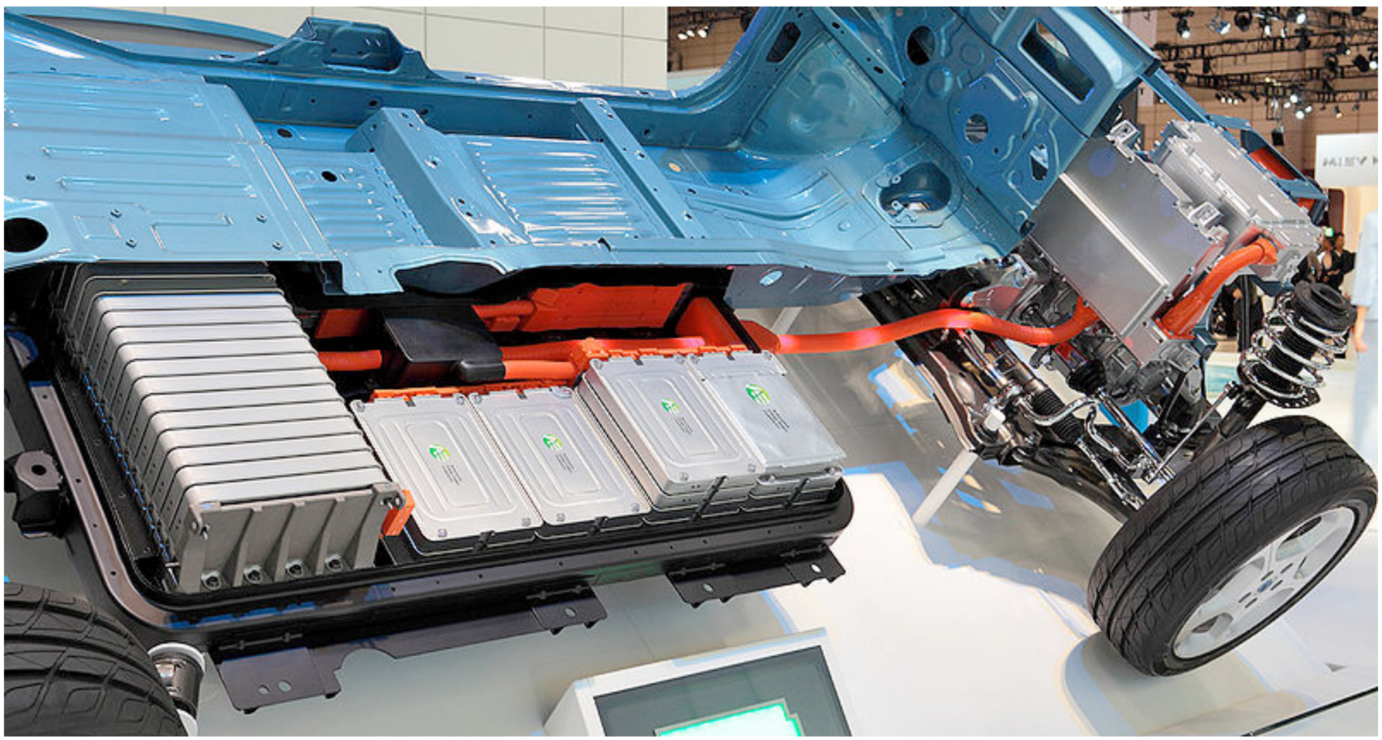
Global investment to reach $122 Billion by 2021 – Pike Research



LiON Declining. $600 down to <$200

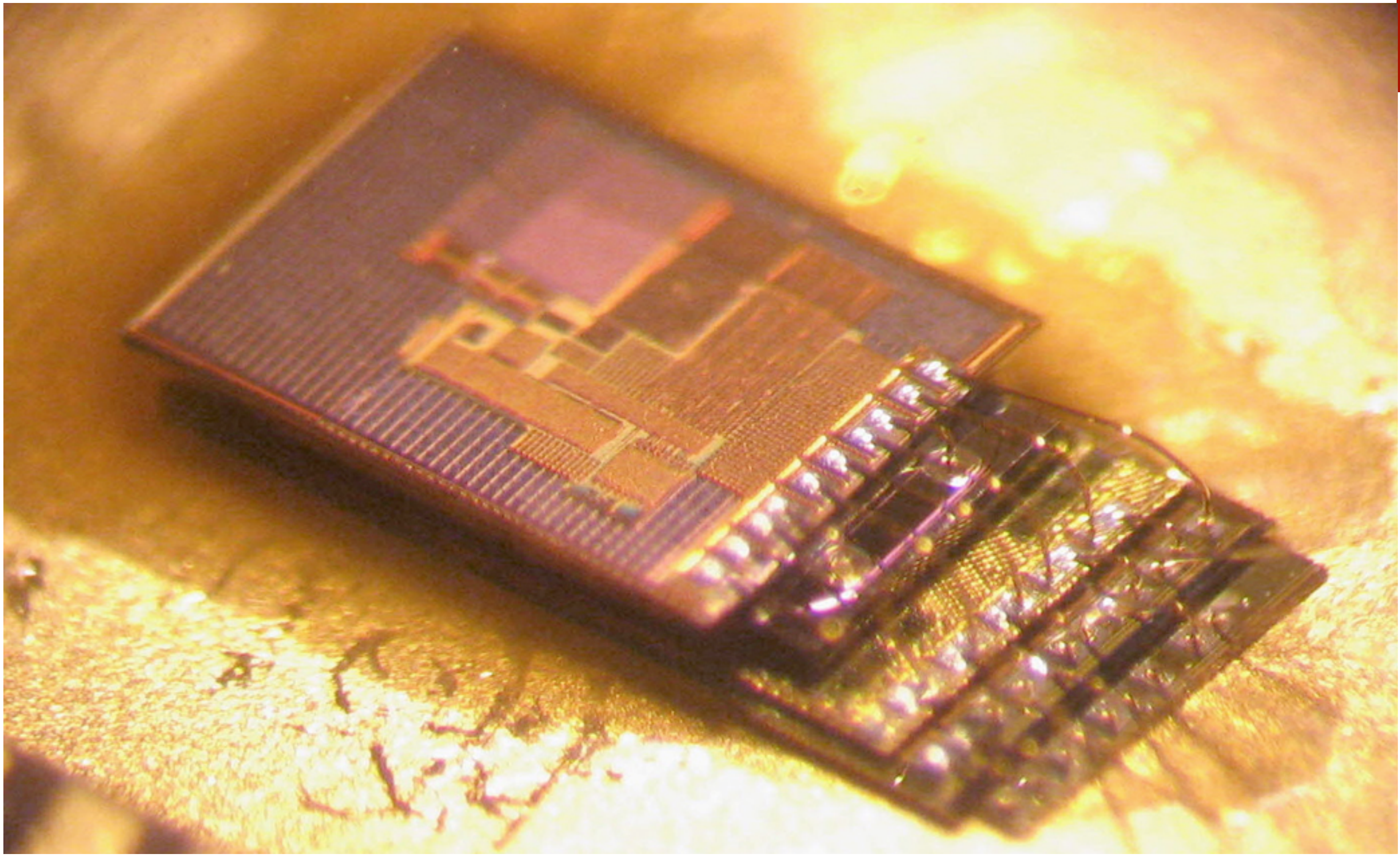
Electric vehicles

- Spur research on lower-cost storage



Nissan Leaf chassis

Pervasive sensing



Michigan Micro Mote

+ pervasive computation

Freescale KL02 microcontroller 1.9 mm x 2.0 mm

allows pervasive control

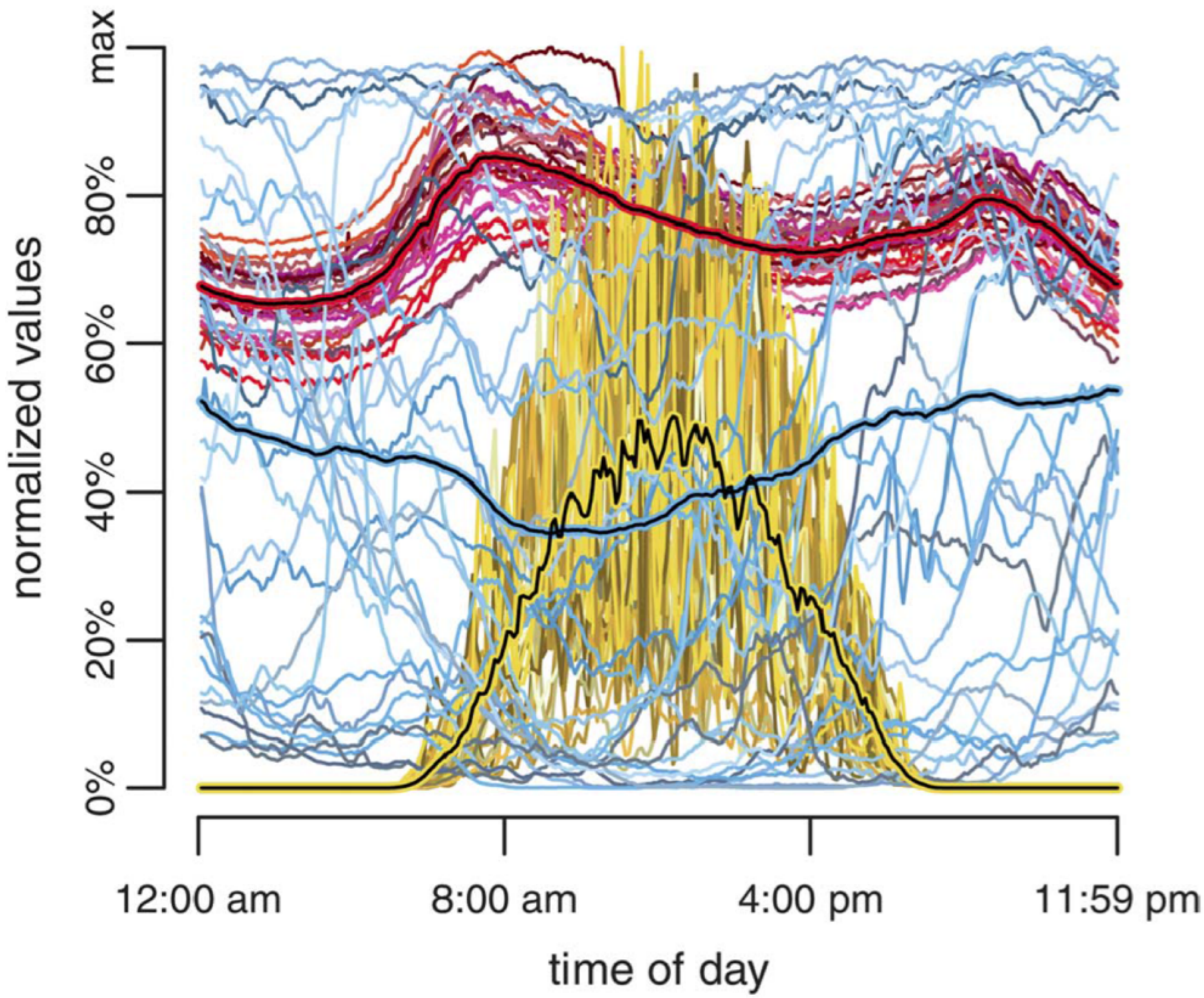
Control 4's EMS-100 in-home display

Current energy systems	Smart energy systems
Fossil-fuel based	Renewables-based
High carbon	Low carbon
Little to no storage	Storage rich
Poorly measured	Sensing rich
Poorly controlled	Control rich
Inefficient	**Energy frugal**

OK, we're done, right?

Maybe not…

1. Need storage…

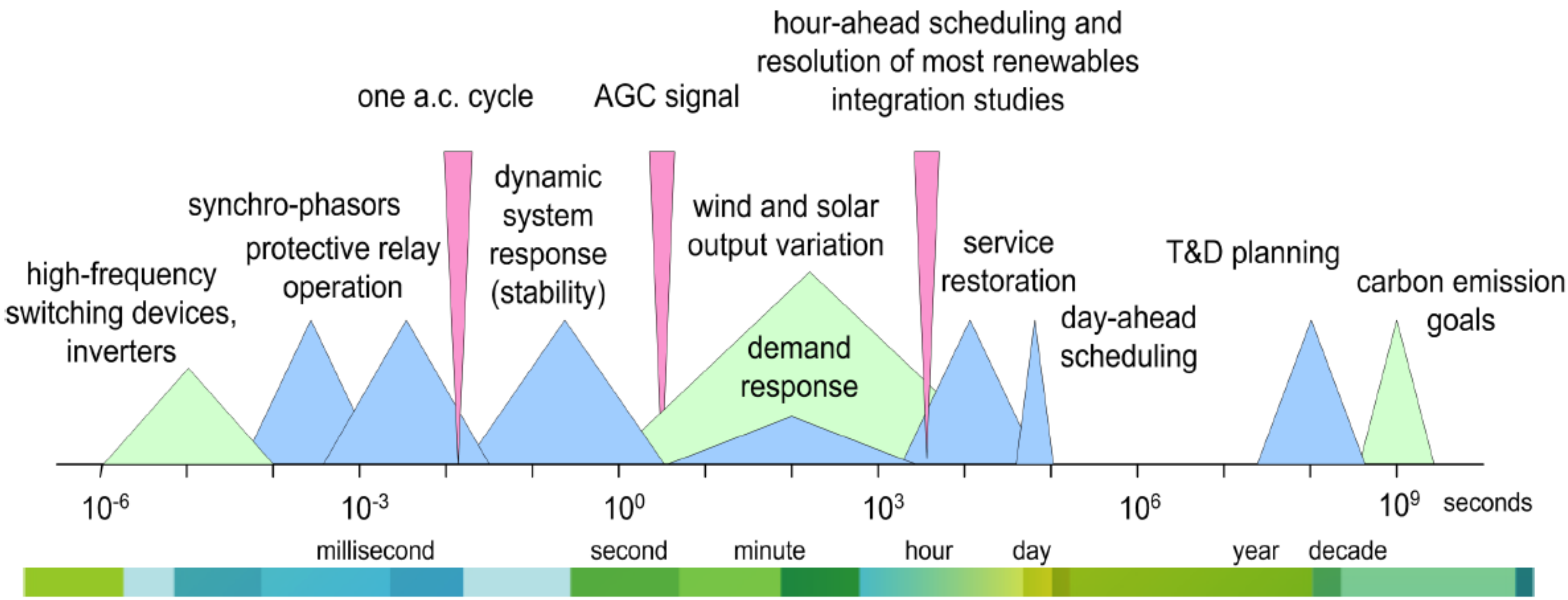


Barnhart *et al*, Proc. Energy and Environment, 6:2804, 2013

… but it is expensive!

- Buying 1 KWh = 10c
- Storing 1 KWh = ~$450!

2. Need control over many time scales



Jeff Taft, Cisco

3. Consumers have no incentive to save

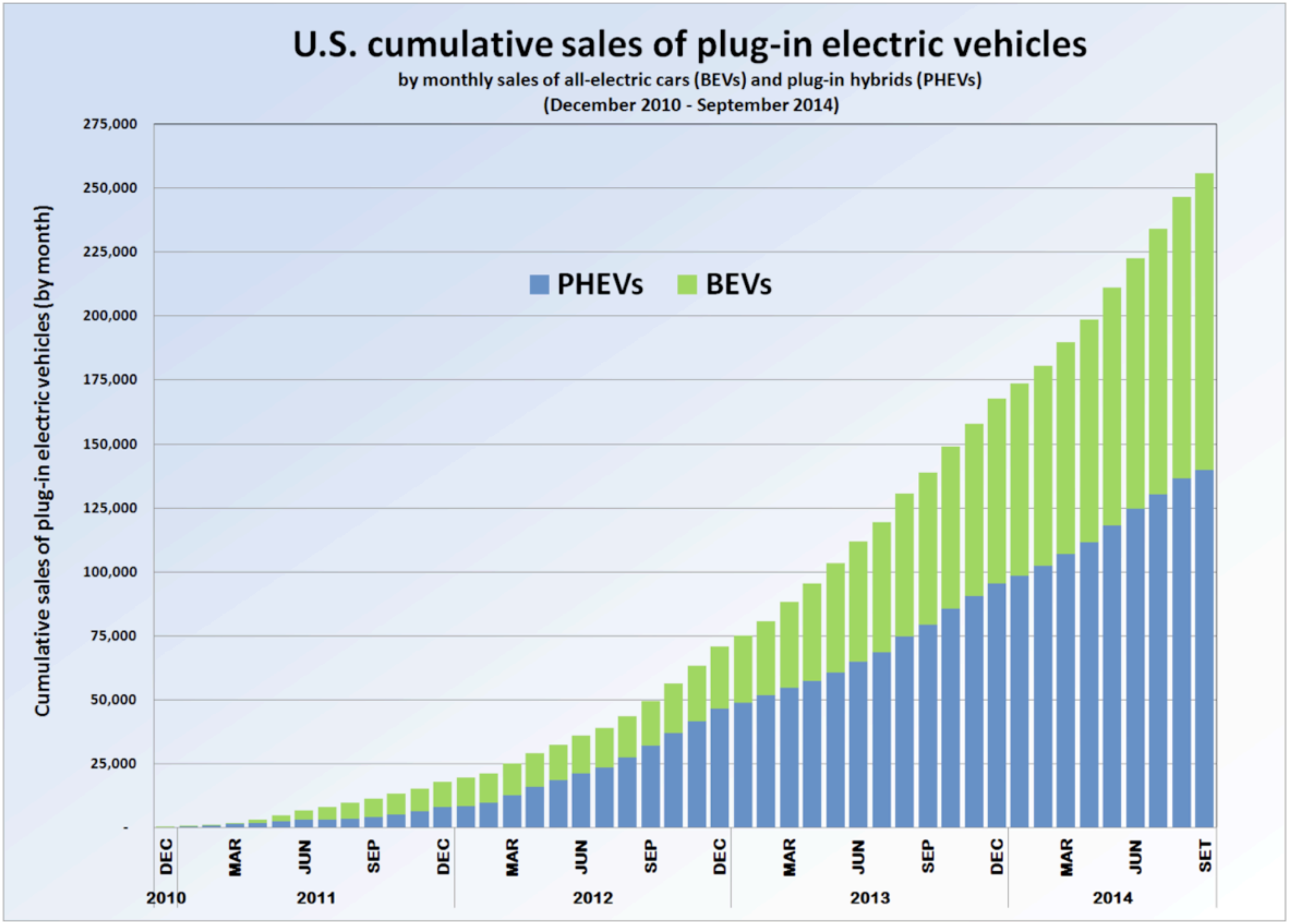
- Energy savings of 10%
  - $10/month

4. Utilities have no incentive to be efficient!

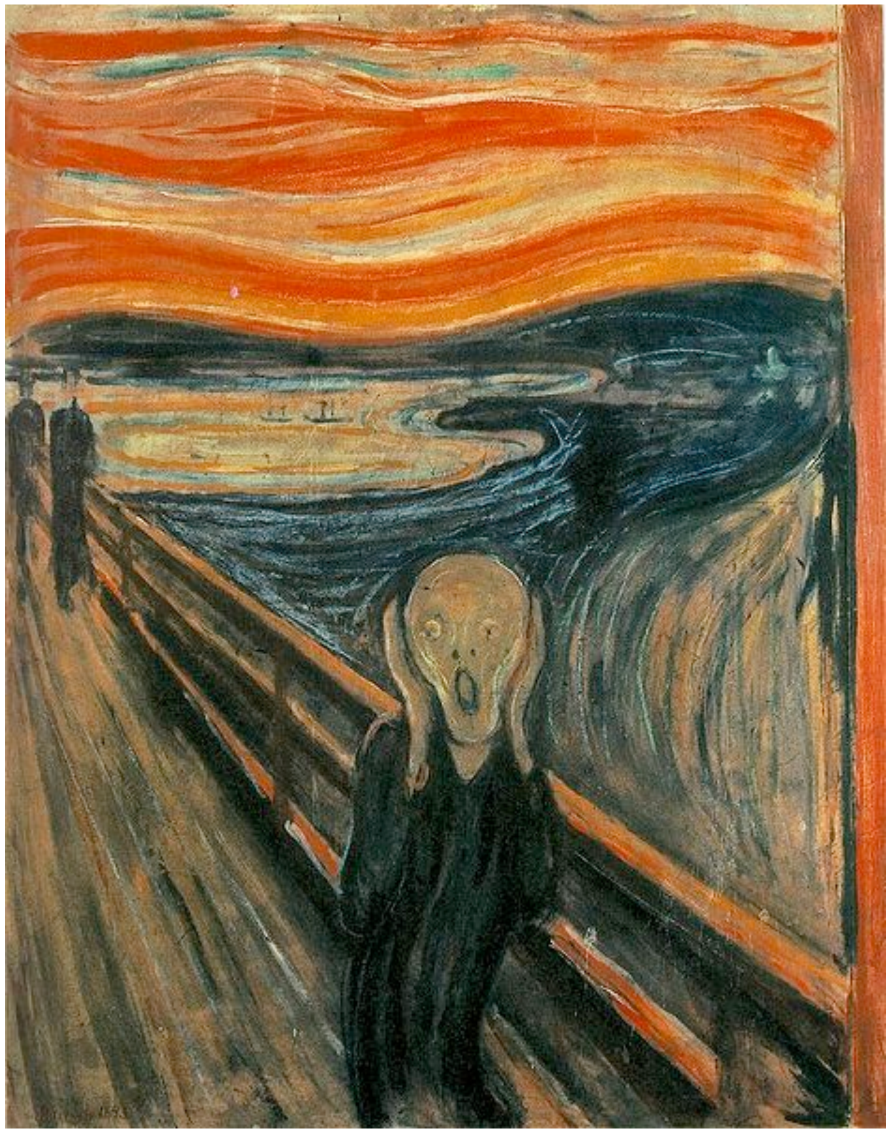
5. Energy data is personal

6. Sensors are energy-limited

7. EV sales are tiny



EV fraction of vehicle fleet in 2014: 0.1%



ISS4E

Mission

WATERLOO
ISS4E

To use information systems and science to

- increase the efficiency
- reduce the carbon footprint

of energy systems

3 Approaches

1. Exploiting equivalency of grid and Internet
2. Designing and building prototype energy systems
3. Mining big data

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

Analytic results

- Transformer sizing
- Optimal control for EV charging
- Minimizing storage size to smooth solar/wind sources
- Optimal participation of a solar or wind farm in day-ahead energy markets
- Modeling of imperfect storage devices and solar power
- Optimal operation of diesel generators to deal with power cuts in developing countries

Joint work with O. Ardakanian, Y. Ghiassi-Farrokhfal, S. Singla, and C. Rosenberg

Mining big data

- Analysis of
  - hourly electricity data from ~26,000 meters (>100 GB)
  - hourly water data from ~27,000 meters (> 100GB)
  - PV and load data every second for 3 months
  - 7 years of carshare rental data
  - 10s of thousands of opinions on EV forums
  - 25+ GB of transportation data
  - …

Conclusions

- Technology is changing the energy infrastructure
- Computer Science has a role to play
- Opportunity for interesting, impactful research

1. Y. Ghiassi-Farrokhfal, S. Keshav, C. Rosenberg, and F. Ciucu. Solar Power Shaping: An Analytical Approach, accepted *in IEEE Transactions on Sustainable Energy,* 2014.

2. S. Singla, Y. Ghiassi-Farrokhfal, and S. Keshav. Using Storage to Minimize Carbon Footprint of Diesel Generators for Unreliable Grids, accepted in *IEEE Transactions on Sustainable Energy*, 2014.

3. O. Ardakanian, C. Rosenberg and, S. Keshav. Quantifying the Benefits of Extending Electric Vehicle Charging Deadlines withGeneration, *IEEE Smart Grid Communications*, November 2014.

4. D. Fooladivanda, C. Rosenberg, and S. Garg. An Analysis of Energy Storage and Regulation, *IEEE Smart Grid Communications*, November 2014.

5. M. Maasoumy, C. Rosenberg, A. Sangiovanni-Vincentelli, and D. Callaway. Model Predictive Control Approach to Online Computation of Demand-Side Flexibility of Commercial Buildings HVAC Systems for Supply Following, *American Control Conference*, Portland, June 2014. **Runner up for Student Best Paper Award**

6. O. Ardakanian, S. Keshav, C. Rosenberg. Real-Time Distributed Control for Smart Electric Vehicle Chargers: From a Static to a Dynamic Study, *IEEE Transactions on Smart Grid*, vol.5, no.5, pp. 2295-2305, Sept. 2014.

7. Y. Ghiassi-Farrokhfal, S. Keshav, and C. Rosenberg. Towards a Realistic Storage Modelling and Performance Analysis in Smart Grids, accepted in *IEEE Transactions on Smart Grid*, 2014.

8. T. Carpenter, L. Golab, S. J. Syed. Is The Grass Greener? Mining Electric Vehicle Opinions. *Proc. ACM e-Energy*, June 2014.

9. Y. Ghiassi-Farrokhfal, S. Keshav and C. Rosenberg. An EROI-Based Analysis of Renewable Energy Farms with Storage, *Proc. ACM e-Energy*, June 2014.

10. T. Carpenter, S. Keshav, and J.W. Wong. Sizing Finite Population Vehicle Pools, *IEEE Transactions on Intelligent Transportation Systems*, Volume 15, issue 3, pp. 1134-1144, June 2014.

Acknowledgements

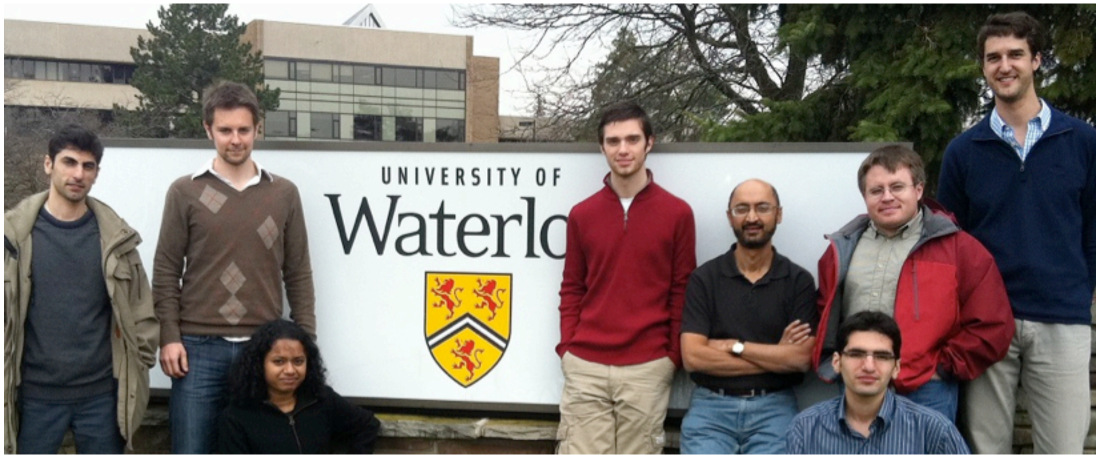
ISS4E Faculty

Co-Director

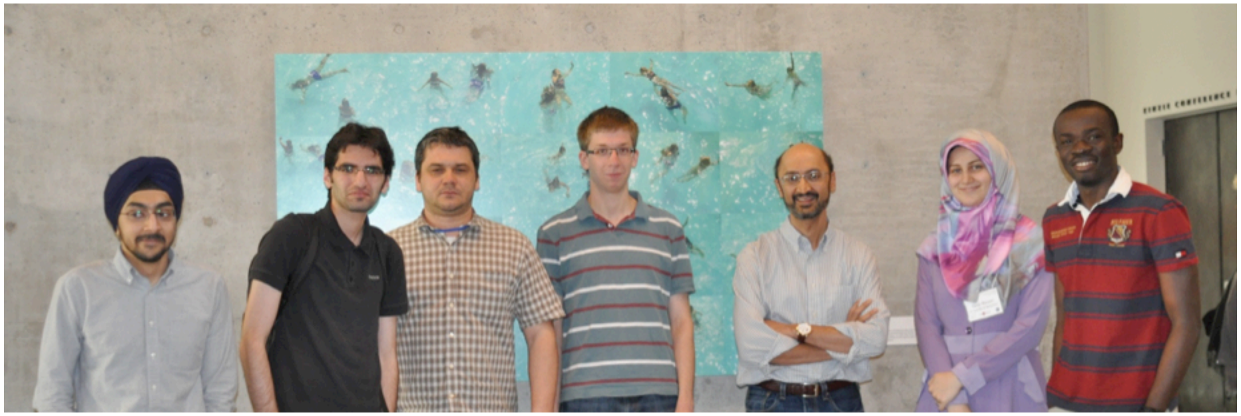





Affiliated faculty



ISS4E students



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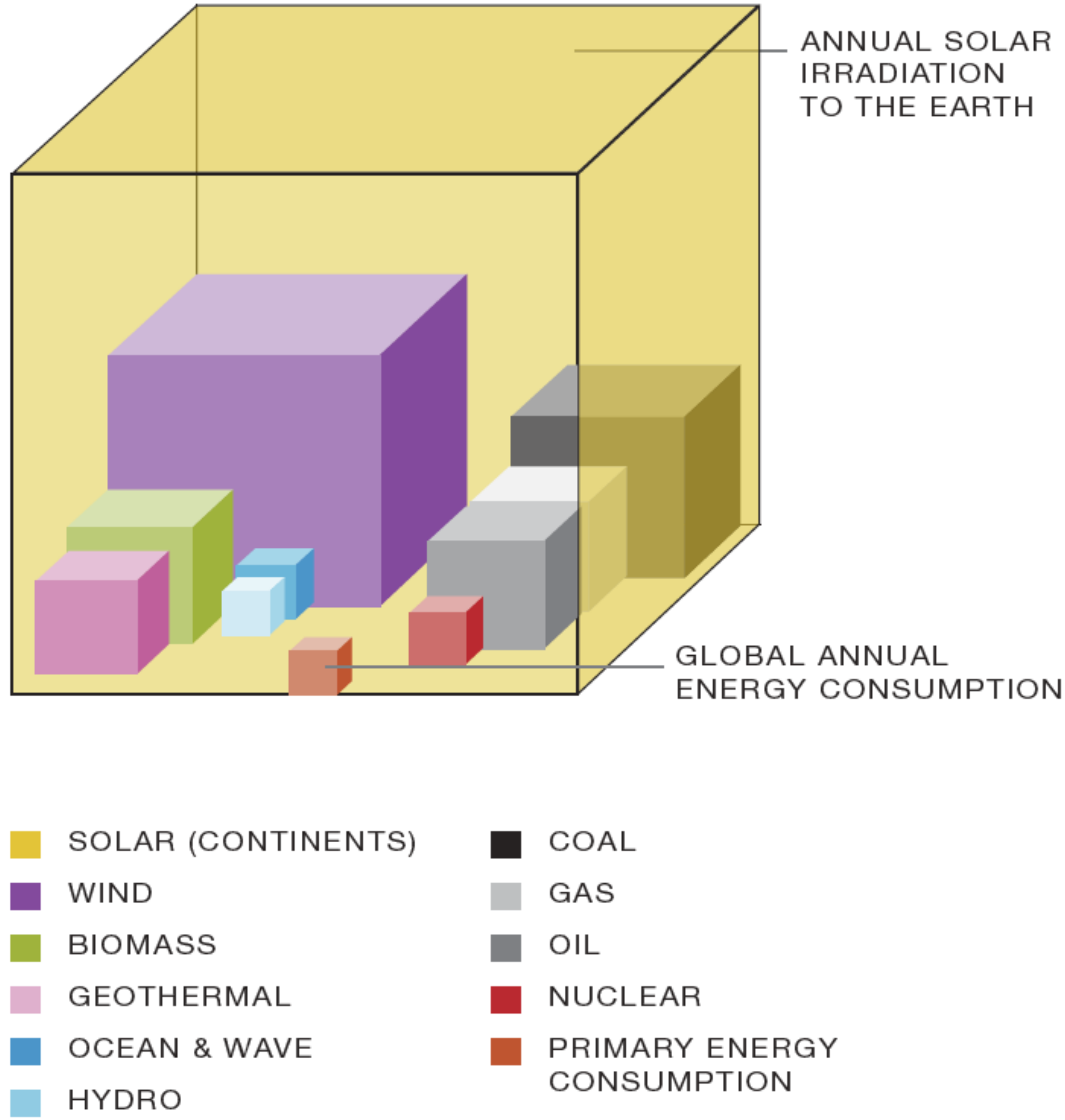
Backup slides

Renewable energy



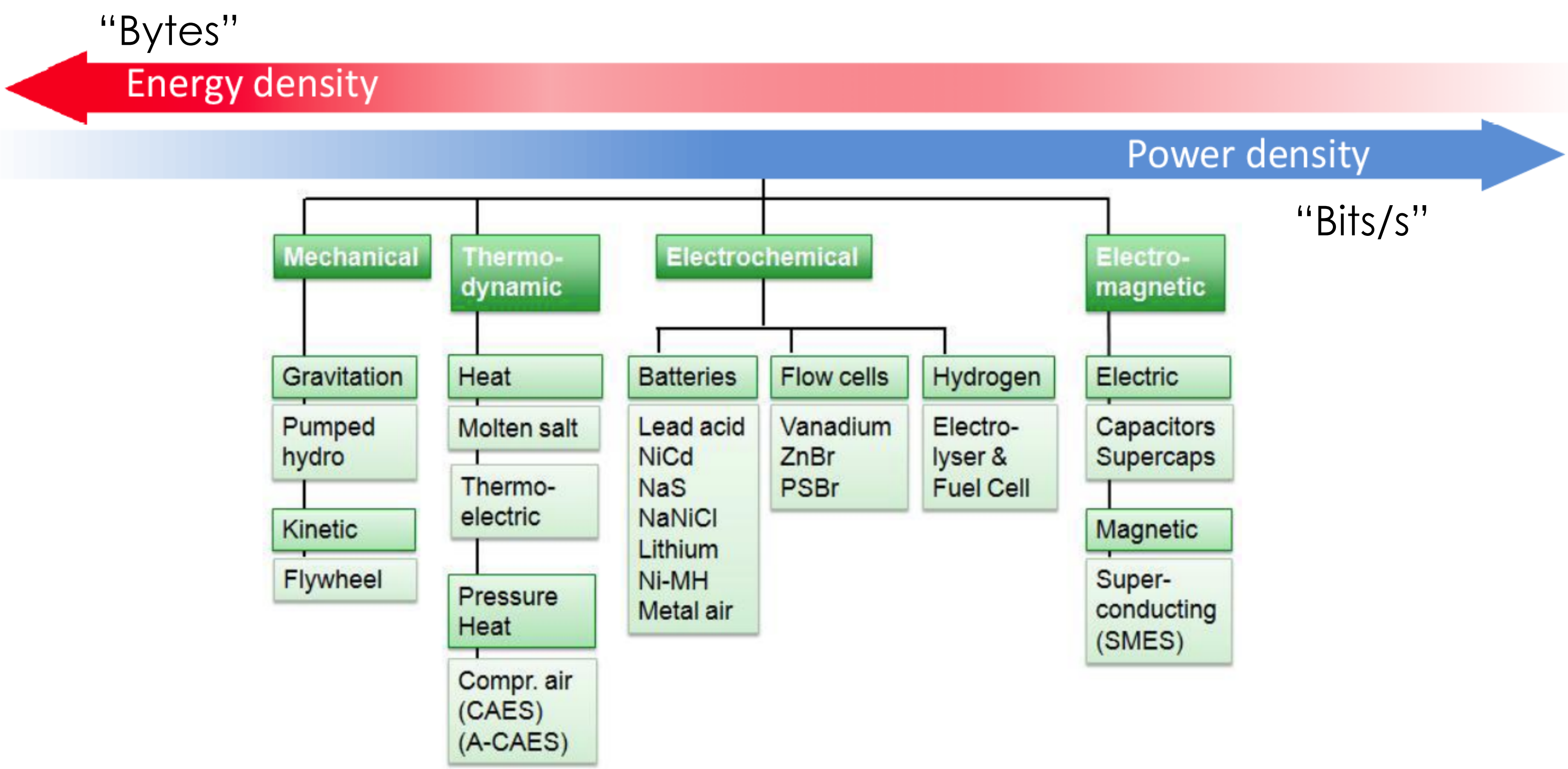
FOSSIL FUELS ARE EXPRESSED WITH REGARD TO THEIR TOTAL RESERVES WHILE RENEWABLE ENERGIES TO THEIR YEARLY POTENTIAL.

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

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

Storage



Graphs adapted from: A. Oudalov, C. Yuen and M. Holmberg, "Energy Storage is a Key Smart Grid Element" | Cigré Symposium The Electric Power System of the Future, Sept. 13-15, 2011, Bologna, Italy