



# Hardware Energy-Efficiency 101

Professor Jon Koomey, Yale University



# Energy-Efficiency Improvements in Computers

- There are underlying technological trends that produce energy-efficiency improvements in computers, on a year over year basis.
- These trends proceed at easily measurable, remarkably predictable, and unusually rapid rates.
- One core trend: the number of transistors on a chip has doubled more or less every two years for decades, a trend that is popularly (but often imprecisely) encapsulated as “Moore’s law.”



# Why are Computers Capable of Improving Their Energy-Efficiency More Rapidly than Other Types of Electrical Equipment?

- The main trend driving towards increased performance and reduced costs in computers, namely smaller transistor size, also tends to reduce power use, which explains why the industry has been able to improve computational performance and electrical efficiency at similar rates.
- If these trends continue (and we have every reason to believe they will for at least the next five to ten years), recent research points towards continuing rapid reductions in the size and power use of computers, particularly mobile computers.
- Research Paper: “Assessing Trends in the Electrical Efficiency of Computation,” published by Dr. Jonathan Koomey, 8-17-2009  
<http://download.intel.com/pressroom/pdf/computertrendsrelease.pdf>

# Figure 1: Improvements in Computer Energy-Efficiency: Computations per Kilowatt Hour (kWh), Over Time



# Predictable Improvement in Energy-Efficiency of Computers

- Computations per kWh doubled every 1.57 years over the entire analysis period, a rate of improvement only slightly slower than that for PCs, which doubled every 1.49 years from 1981 to 2009.
- The computer industry has been able to sustain rapid improvements in computations per kWh over the past sixty years, and we expect those improvements to continue in coming years.
- The research suggests that doubling of computations per kWh every 1.6 years is the long-term industry trend, but we believe (because of the large remaining potential for efficiency) that achieving faster rates of improvement is within our grasp.



## Implications of this Research for Creating Programs to Capitalize on Improvements in Computer Energy-Efficiency

- Whether performance per CPU can grow for many years more at the historical pace (doubling every 1.5 years or so) is an ongoing subject of debate in the computer industry (Bohr 2007), but near-term improvements are already “in the pipeline.”
- Regardless: current new computers deliver computations more energy-efficiently than older computers, and future new computers will be more efficient than today’s. Mobile computers in particular will benefit from this trend.
- Other trends improve efficiency of computers also, including the shift to laptops, the shift away from CRT screens, and the rapid improvements in power management when the computer is not being used.