Energy and Future Society
From Science and Engineering Perspective

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INTRODUCTION
Your Daily Life

- Work
  - Motion Power
  - Heating/Cooling
  - Light
  - Communication

- Home

- Outdoor
  - Motion Power
  - Heating/Cooling
  - Light
  - Communication
Modern Society

- **Industry / Business**
  - Factories, Offices, etc.

- **Government**
  - Critical Infrastructures
    - Safety: Military, Surveillance System, and etc.

“All Sectors of Society are Fueled by Electrical Energy”

(e.g., Effect of Hurricane Sandy, Power Outages)
Future Society

- Internet of Things (IoT)

“Computers and Sensors Powered by Electricity”
More Energy!!

Constant Increase in Energy Demand is Inevitable

(Even greater for developing nations!)

How will we meet rising demand for energy?

U.S. demand for energy is expected to increase 14-28% from 2005 to 2030

Source: Annual Energy Outlook, EIA (U.S. Energy Information Administration), 2008
However... Can we Get There?

Economic Growth and Technology Advancement is **constrained** by...

1. Climate Change (Protect Environment)
2. Rising Energy Cost (Oil, Electricity)
3. Physical Limits of Energy Storage Capability
SOME RECENT ARTICLES
Costs of Climate Change May Prove High for Future

Our descendants will pay a higher price for greenhouse gas build-up as real costs are updated over time.

LONDON – Economists and scientists may have seriously underestimated the "social cost" of carbon emissions to future generations, according to a warning in the journal Nature.

Social cost is a calculation in US dollars of the future damage that might be done by the emission of one metric ton of carbon dioxide as greenhouse gas levels soar and climates change, sea levels rise and temperature records are broken in future decades.

How much would society save if it didn't emit that ton of carbon dioxide? One recent federal estimate is $37. Such a measure helps civil servants, businessmen and ministers to calculate the impact of steps that might be taken.

Soot and Smog Put China's Babies at Risk

China's smoke-belching coal plants and heavy traffic may be signs of a bustling economy but health experts fear the country's dirty air is hurting its infants.

China's smoke-belching coal plants and heavy traffic may be signs of a bustling economy but health experts fear the country’s dirty air is hurting its babies.

Evidence is mounting that coal and car emissions in China, as well as other developing countries, are raising the risks of premature babies, low birth weights and neural tube defects.

“Their cities are in big trouble and so are their babies,” said Richard Finnell, a professor at the University of Texas, Austin, who has studied birth defects in North China.
Cost of Climate Change

CARBON’S COSTLY LEGACY
Economic models of climate change project that resulting damage worldwide (A) will increase with future emissions and may cost several per cent of global gross domestic product (GDP) with the warming expected by 2100. Uncertainties in future socio-economics, emission rates and climate impacts result in a range of estimates of the social cost of carbon, which is also affected by the choice of ‘discount rate’ used to convert future harms into today’s money (B).

A PROJECTED DAMAGES

B SOCIAL COSTS FROM US GOVERNMENT ANALYSIS

*Shaded regions indicate 5% and 95% confidence intervals for FUND 3.8 and PAGE09, and a high-low range for CRED 1.4.

Cost of Climate Change

- Environmental Changes

Effects...
- All Sectors of Society
  - Business, Industry, Residence
- Many different aspects
  - Safety, Health, Money, and etc.

Millions of China's Farmers Now Buy Climate-Change Insurance

Policymakers have persuaded farmers in China to buy insurance against losses in agriculture, which is at risk mainly due to climate change.

ClimateWire
Apr 22, 2014 | By Coco Liu and ClimateWire

Weeks before the harvest started last summer, Li Ping’s rice paddies were hit by extreme weather. Temperatures of 95 degrees Fahrenheit baked Longtan village in north China for over a month, causing leaves yellowing and damaging grain production. As a result, Li’s rice yields decreased by 20 percent compared with normal years.

But Li did not struggle to raise money for his next planting, which he did after previous crop failures. Instead, the 51-year-old farmer waited at home for the money to come.

"I have insured my rice production since 2009," Li said. "The compensation I got didn’t recover the total losses, but it did remove part of my financial pressure."

Farming on the terraced fields in China becomes less risky with insurance. Credit: David Woo via Flickr
Rising Energy Cost

Average Retail Price of Electricity, Monthly
Indexed to Jan 2001 as percent
Percent

Average Price of Oil, Monthly

Nominal
Real (April 2011 US dollars)

May 1987 – April 2011 monthly average Brent spot prices
Conversion to April 2011 dollars uses US CPI for All Urban Consumers (CPI-U)
Sources: Energy Information Administration and Bureau of Labor Statistics

Constant Increase

4x

Constant Increase + Unstable
Rising Energy Cost

• Food for Fuel?
  – Cellulosic Biofuel
  • From agricultural wastes, wood, household trash and energy grasses
  • More environmentally sustainable than biofuels from food crops like corn and soybeans
Limited Energy Storage

Option 1: Accept

Option 2: Denial/Panic
Limited Energy Storage

“Why Your Battery Life is So Terrible?”

What We Want!

• Cleaner Environment

• More Energy at Lower Cost

Q: Anything Else?
WHAT CAN WE DO?
A. Problems

A1. Climate Change

A2. Rising Energy Cost

A3. Limited Energy Storage

B. Solutions

B1. Create Clean Energy

B2. Efficiently Using Energy

B3. Higher Energy Capacity
B1. Create Clean Energy

• “Renewable” Energy
  – Solar, Wind, Hydro(river, tides, waves), geothermal, biomass

• Required Technology: Electronics / Physics / Chemistry

Note: “run-of-the-river” hydro has some critical drawbacks due to its effect on environment.
Over time, the electricity mix gradually shifts to lower-carbon options (led by growth in natural gas and renewable generation)

B1. Create Clean Energy

Non-hydro renewable generation more than doubles between 2012 and 2040

B1. Create Clean Energy

Solar Power Grows 400 Percent in Only 4 Years

More than half of the added capacity comes from home and business owners.

Goal: 35% by 2020, 50% by 2030, 65% by 2040, and 80% by 2050
B1. Create Clean Energy

• “Half the world's new generating capacity has been renewable since 2008.”

• “Today, three of the world's top four economies—China, Japan, and Germany, as well as India—produce more electricity from non-hydro renewables than from nuclear power.”

• “Renewable energy sources accounted for 5.8% of the global energy production in 2010 (expected 11.8% in 2020, 17.7% in 2030).”

• Q: What about Korea?
  – 2010: Thermal - 65%, Nuclear - 31%, Renewable (including hydro) - 3%
  – Funded but not consistent / Cost effectiveness of Nuclear Power
  – Renewable Energy Industry lag behind global peers (due to lack of gov’t support) c.f., China $332 billion, Korea $2.54 billion in 2012


• Required Technology: Chemistry / Material

Chemical Energy ↔ Electrical Energy

~ mAh

~ Ah

~ MAh

There is a “LITTLE” problem
(Limited Capacity and Lifetime)
B2b. Sustain Energy Capacity

• Energy Harvesting (Portable Scale)
  – Thermoelectric, *Piezoelectric* (Mechanical → Electricity), Electrostatic, *Blood Sugar* (oxidation), and many more...

• Wireless Charging
  – Inductive
  – Resonance
B2b. Sustain Energy Capacity

- Energy Harvesting!
  - A team of researchers in South Korea have created a transducer that translates water motion—from toilets, raindrops, or other water-based uses—into electricity.
  - Korea Electronics Technology Institute (KETI)

B2b. Sustain Energy Capacity

- Induction-based Wireless Charging
  - Transfer energy using electromagnetic **field**
  - Maxwell’s Equations
B2b. Sustain Energy Capacity

• Resonance-based Wireless Charging
  – Transfer energy using oscillating magnetic fields ("WiTricity")
  – 1997 @ MIT

Source: WiTricity, URL: www.witricity.com
B3. Efficiently Using Energy

• Energy Efficient Internet
  – Communications/Networks
  – Wireless Devices (Mobile Phone, Sensors)
  – Data Centers

• Upgrade Century-Old Power Grid
  – “Smart Grids”

• **Required Technology:** Computer Science and Engineering (Algorithms, Optimization, Data Analysis, Control, Communication, Network, Devices, and etc.)
RESEARCH @ SMART ENERGY LAB

http://www.sel.cs.sunykorea.ac.kr/
Scope of Research

“Communications and Networks”

1. Energy Efficient Wireless Communications and Networks
   – Scheduling Problem
   – Synchronization Problem
   – (more to explore…)

2. Smart Grid Communications and Networks
   – Optimization of Supply and Demand
   – Integration of Electric Vehicles
   – Data Analysis and Security
ENERGY EFFICIENT WIRELESS COMMUNICATIONS AND NETWORKS

- Sleep Scheduling
- Distributed Clock Synchronization
Energy Efficient Wireless Protocols

High Energy Consumption in Idle State

- Radio States: Tx / Rx / Idle / Sleep

Node A
- Power
- Idle
- Rx
- Tx
- Idle

Node B
- Power
- Idle
- Tx
- Rx
- Sleep
- Idle

\[ P_{\text{Idle}} \approx P_{\text{Rx}}, \quad P_{\text{Idle}} = 0.5 \cdot P_{\text{Tx}} \]
Energy Efficient Wireless Protocols

Q: **HOW** to solve the idle listening problem?

**A: Sleep Scheduling**

*(when to tx/rx/idle/sleep?)*

- Significantly low power consumption
- But, communication not possible
Asynchronous Sleep Scheduling

• Sleep Scheduling Protocol
  – Turn off radio (sleep) whenever possible to save energy

Case 1: Node B

Case 2: Node B

Synchronous

Asynchronous

+ time shift
Asynchronous Sleep Scheduling

- Sleep Scheduling Model (Slotted Frames)

Node A:
- \( E_A = \{1, 2, 3, 4, 5\} \)
- \( n_{on} = 5 \)
- \( n_{off} = 4 \)

Q: How to achieve required connectivity with the smallest number of active slots?

Solution Approach:
"Combinatorial Method" (+ hierarchical structuring)

Distributed Clock Synchronization

• Lower synchronization error → reduce energy cost due to inaccurate timing of neighbor discovery (guard intervals)

• Clock compensation Algorithm: asynchronous, intermittent, and long delayed connections
Distributed Clock Synchronization

Q: How to achieve smallest relative time differences?
(asynchronous, intermittent, and long delayed connections)

Solution Approach:
"Distributed Consensus"
(+asynchronous, intermittent, delay)

SMART GRID COMMUNICATIONS

- Introduction: Smart Grid
- Wireless Technology for Microgrid
- Bi-directional Energy Delivery using Electric Vehicles
Current Power Grid

Reliable Power

High Quality Power

One Direction

Generation Transmission Distribution Consumption
Modernizing Power Grid

“A major national priority for many counties around the world!”

• Goal...
  – Cost-effective Production and Delivery of Electricity
  – Provide Consumers with Electronically Available Information
  – Permitting Greater use of Renewable Sources
  – Improve the Reliability and Service
  – Support a Growing Fleet of Electric Vehicles
Smart Grid

Information Technology

Measurement and Control

Digital Communication

Sensing

Bi-Directional

Generation
Transmission
Distribution
Consumption
**Smart Grid - Motivations**

- **Transmission and Distribution Efficiency & Reliability**
  - Estimation along the line
  - Automated Sensors and Control
  - Dynamic optimization of voltage levels and reactive power
  - + Fault detection
Smart Grid - Motivations

- **Peak Shaving**
  - Generation capability designed to match infrequent peak demands → Waste
  - Dynamic pricing or direct control via *Smart Meters*
  - Shift on-peak periods to off-peak periods

Adaptive Control

<table>
<thead>
<tr>
<th>AM</th>
<th>PM</th>
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<tbody>
<tr>
<td>peak</td>
<td>peak</td>
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<tr>
<td>new peak</td>
<td>new peak</td>
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Power Demand (W)

Time of the day (h)
Smart Grid - Motivations

- **Flexibility & Sustainability**
  - Distributed generation from sustainable/clean sources (wind, solar, and etc.)
  - Microgrids (localized power grid) can increase reliability and eliminate transmission loss
Smart Grid - Motivations

- **Electric Vehicles**
  - Reduce dependence on oil
  - US Department of Energy: “idle capacity of electric power grid” = “70% energy cars and light trucks”
Tesla Sedan Is Ranked ‘Best Overall’ by Consumer Reports

By Jeff Plungis  |  Feb 26, 2014 6:31 AM GMT+0900  |  10 Comments  |  Email  |  Print

Elon Musk’s Tesla Motors Inc. (TSLA) has earned the adoration of investors and the highest U.S. safety ratings. It can also add the honor of having the best-reviewed car of the year by automobile testers at Consumer Reports.

Tesla’s battery-powered Model S beat the Audi A6, Toyota Prius and BMW 328i in Consumer Reports’ annual ranking, becoming the first U.S. car to receive a “best overall” pick, the independent product-testing magazine said today. The reviewers singled out the Model S for its “blistering acceleration, razor-sharp handling, compliant ride and versatile cabin.”

“It’s truly a groundbreaking car,” Jake Fisher, Consumer Reports’ director of auto testing who
Our Research Focus

- Decentralized Microgrid Control
  - Reducing information sharing/synchronization delay using wireless communications
- Plug-in Hybrid Electric Vehicle (PHEV)
  - Optimal charging/discharging policy considering vehicle mobility
- Data Analytics and Security
Decentralized Microgrid Control

• “Microgrid”: Localized power generation, storage, and consumption
  – Low-cost, short-range wireless communication (e.g., ZigBee or WiFi)
  – NO central controller for cost and reliability concerns (Problem: each agent (or node) may need some info for decision making)

Solution Approach:
"Consensus Theory"
(+ cost optimization, dynamic input data)

V2G Optimization

• Vehicle to Grid (V2G) Concept
  – The V2G concept is that EVs can send power to the electric grid. For battery vehicles (BVs) and plug-in hybrid electric vehicles (PHEVs), the power connection is already there.
V2G Optimization

- **Objective:** daily energy cost minimization of vehicle owners
- **Strategy:** draw “cheap” energy from the grid, and vice versa

**Ontario electricity time-of-use (TOU) price**

**A Question:** At 1:00pm, I am at work and have 6 kWh energy left. How much shall I buy/sell?

**Solution Approach:**

"Stochastic Inventory Theory" (+ DTN routing, approximation, dynamic programming)

Data Analytics and Security

• Large Amount of Data
  – 2017: 40% of utilities with smart metering solutions will use cloud-based big data analytics to address asset-, commodity-, customer- or revenue-related needs
  – 2020: 1 billion expected smart meters worldwide (= approx. 60% of all installed meters)

• Goal
  – Make Good Use of Data
    • integration with other forms of data, such as weather, demographics, network condition etc.
    • Data Analytics Entities: Enterprise, Grid Operations, Consumer
  – Provide Secure and Privacy-Preservation of Data **

Other Research Areas

• **Energy Efficiency**
  – Data Centers
    • Reducing transmission
    • Reducing data processing
  – Mobile Phones
    • Turning off idle processes
    • Transmit wireless under good channel condition
    • Data/Process offloading
  – Mobile Communications
    • Turning off base stations
    • Adaptive
  – Sensors
    • Turning off wireless
    • Network lifetime maximization
    • Energy harvesting

(and many more ... )
Concluding Remarks

• **Shift towards Greener Society is Inevitable**
  – Increase in Environmental Awareness
  – Higher/Broader Requirement for Computation and Communication
  – Rise in Energy Cost
  – Limited Energy Storage

• **Energy Efficiency is a New Performance Metric**

• **Many Opportunities for Energy Research**
  – Create Clean Energy (e.g., Renewables)
  – Efficient Use of Energy (e.g., Energy Efficiency, Smart Grids)
  – Higher Capacity of Energy (e.g., Advanced Battery, Wireless Charging, Harvesting)

• **Interdisciplinary Research**
  – Electronic, Network, Communication, Data Science, Security, Policy, etc.
If you are interested...

• Smart Energy Lab, URL: http://www.sel.cs.sunykorea.ac.kr/


• Rocky Mountain Institute, URL: http://www.rmi.org

• U.S. Energy Information Administration (EIA), URL: http://www.eia.gov

• And tons more...
Any Question?

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