Critical Energy Technologies of the Future

Knowledge To Go

Michael E. Webber, Ph.D.
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Energy Is Good: It Enables Things We Like and Need

- Transportation
- Industry
- Home Comfort
- Clean Water
- Agriculture
The Global Map of Electricity Consumption and Wealth Are Nearly Identical

Source: NASA (2012)
Energy Consumption and Affluence Are Correlated

Per Capita Gross Domestic Product vs. Energy Consumption

Source: World Bank 2011 (2005 Data) • Graphic: Michael E. Webber, The University of Texas at Austin

Per Capita GDP [PPP $2005] x1000

Per Capita Energy Consumption [MMBTU/Year]
Energy Has Drawbacks, Too
The Energy Problem Is Comprised of Three Converging Crises

- Three energy crises:
  - Resource Depletion
  - Environmental Degradation
  - National Security & Violent Extremism

- All three are related and amplify each other
Prominent Media Attention to Oil Has Raised Questions About Resource Depletion, Costs, and Reliability of Supplies
Environmental Issues Are Also Front and Center

April 2006

March 2006

September 2004
The National Security Implications of Energy Are Important

Source: Economist, March 2011
Our national dependence on oil... makes us intervene in oil-rich regions... which just furthers... a military so big it's the biggest oil consumer in the nation... which means we need a really big military.
Pledging to Get Off Foreign Oil Is A Decades-Long, Bipartisan Tradition
The USA Must Balance Three Priorities While Addressing the Energy Problem

Most options for new fuels or technologies solve any one or two priorities, but not all three.
What Is The Status of Energy Today?
Approximately 1 Billion People Suffer From Chronic Hunger

Source: UN World Food Program
Approximately 1 Billion People Do Not Have Access to Clean Drinking Water

- Plus 80% of global population at high risk of threats to water security

Source: UN, Nature
Approximately 2.5 Billion People Do Not Have Access to Sanitation

Source: UN
Approximately 5 Billion People Do Not Have Access to Computers or the Internet

Source: Internet Worldstats
At least 2 Billion People Do Not Have Access to Telephones

- There are 5 billion mobile phone accounts globally
  - Maybe an allegory for distributed energy leapfrogging centralized energy?

Source: ITU
There are only 600 million cars and 250 million trucks globally

Source: WorldMapper
All Those People Want…

• Food
• Water
• Sanitation

• Computers
• Phones
• Cars
Changing Our Energy Mix is One Part of the Solution
Energy Transitions Have a Few Features

• They are more typical than we might expect
• They take a long time
• They tend to follow a path towards decarbonization
Energy Transitions Take a Long Time

Source: EIA
©M.E. Webber, UT Austin (2012)
Energy Transitions Show a Trend of Decarbonization
Energy Systems Can Change
The Stars at Night, Are Big and Bright....
Global Energy Trends
The Energy Transition Will Be Comprised of Three Shifts

• A change in total demand for energy
  – Population growth pushes total demand up
  – Economic growth pushes per capita demand up

• A change in our end uses of energy
  – Electrification
  – Motorization
  – Urbanization
  – Industrialization

• A change in our sources of energy
  – Domestic sources
  – Low-carbon sources
  – Sustainable sources
There Are Six Trends And Forcing Functions to Watch

- **Pressure From Capital Markets**: Energy will become smaller/modular, quicker to build, and with higher utilization

- **Pressure from Economists**: Energy markets will become liberalized

- **Pressure From Regulators**: Energy will get cleaner
There Are Six Trends And Forcing Functions to Watch

• Pressure From Popular/Cultural Forces: Energy will become more sustainable/renewable

• Pressure From Utilities: Energy will become smarter, resilient and flexible

• Pressure From Consumers: Energy will become democratized and will stay affordable
Energy Will Become Smaller/Modular, Quicker to Build and More Highly Utilized

- Loan sizes of $100Ms instead of $1Bs
  - Large nuclear goes to modular nuclear
  - Large coal goes to natural gas combined cycle
  - Wind proceeds as before
  - Rooftop solar goes to utility scale solar farm

- Loans will emphasize 1-3 year build out
  - Nuclear and coal on hold
  - Natural gas, wind and solar proceed

- Capital efficiency will increase from 46% to 80-90%
  - Storage, load-leveling/shifting, demand response
Energy Markets Will Become Liberalized

• More competition in the power markets
  – Entrenched interests are not excited

• More markets
  – Ancillary services (Storage, Firming power)
  – Will transmission bottlenecks remain?

• More innovation

• Market dynamics
  – Supply and demand will affect prices
  – Signals will drive consumer behaviors
Energy Will Become Cleaner

• Fuel switching
  – Renewables & natgas will compete w/coal & oil

• Scrubbing
  – Growth market for NO$_x$, SO$_x$, Hg (and CO$_2$?) scrubbers

• Temporal Sensitivity
  – Reducing emissions by time of day and time of year
  – Real-time pricing, environmental dispatching

• Water
  – Reduced water intensity of energy (for power plants and fuels extraction)
Energy Will Become More Renewable and Sustainable

- Support for renewables
  - Regulatory-driven programs (RPS, CES) ~$100Bs
  - Consumer choice programs (GreenChoice)
  - Tax supports (PTC, ITC)

- Large-scale implications
  - New infrastructure for transmission
  - Wealth generation for rural landowners

- Impacts for fossil fuels
  - Push for “new” renewables (waste coal and RNG)
  - Additional barriers to conventional fossil fuels
Energy will become smarter, resilient and flexible

• Large scale (~$100Bs) of investment in the “smart grid”
  – Massive roll-out of smart meters
  – Smarter transmission & nodal markets
  – IT opps: mobile apps for control & awareness

• For the Utility:
  – On-call demand reduction
  – Better response times to outages

• Consumers:
  – New smart appliances
  – Return of the ESCOs (Energy Service Companies)
Energy Will Become Democratized

- Distributed Generation:
  - Solar PV rooftop
  - Natgas microturbines and fuel cells
  - Ground source heat pumps
  - New market entrants

- Distributed Electricity Storage:
  - EVs
  - Garage battery banks

- Distributed Control:
  - Smart appliances, meters, and mobile apps
All Six Trends Point To A Handful of Winners

- Fuels:
  - Near: natural gas, wind, solar PV, geothermal
  - Far: small nuclear, small hydro, microharvesters

- Technologies: storage, “smart”, IT

- Landowners

- Service companies
  - The industry will shift from a cost basis to a value basis
All These Forcing Functions, Trends, and Looming Shifts Present Interesting Analytical and Research Opportunities
The US Energy Situation Is Improving Quickly

- Domestic production is up
  - Oil, gas, wind, solar, geothermal, bio

- Consumption is down

- Imports are down
Webber Prediction: Within 1-2 Decades, Natural Gas Will Overtake Petroleum As The Most Common Energy Source in the USA
Is This Revolution The Result of Market Triumphalism, Good Policies, Disruptive Technologies, or Something Else?
For The First Time Since The 1960s, Energy Technologies, Policies, And Markets Are Aligned

• Market triumphalism: the shale play is almost entirely on private lands with private companies and was triggered by high prices

• Supportive government policies:
  – DoE R&D investments throughout the 1970s to 1990s kickstarted the whole trend

• Disruptive Technologies: advancing 1930s and 1950s technologies is a 2000s idea whose time has come
Perhaps The Same Method Of Public-Private-Technology Partnership Could Be Used To Solve Our Healthcare, Financial, Monetary, And Educational Crises?
There Are Other Winners Long Term
The Shortcomings of Abundant Domestic Resources: Coal, Solar, Wind and Bio

• Coal is abundant and cheap
  – but dirty and carbon-intensive

• Solar and wind are abundant
  – Generally where the people are not
  – Often available whether you need it or not
    • Solar is more predictable than wind, but still intermittent

• Biofeedstocks are in difficult forms to process

• Waste streams are abundant
Defining the Critical Technologies

• Which technologies allow us to either

  1. Develop domestic resources (coal, wind, solar, bio), or
  2. Import energy from “friendly” nations

  ...without causing environmental problems, or running into supply shortages

• Which technologies can bridge the gaps and enable win-win solutions?
There Are Several Critical Technologies For the Long Term

• Grids
  – Supergrids for efficient long-haul transmission
  – Smart grids for optimization of local distribution

• Storage
  – Large-scale for integrating renewables
  – Small-scale for electrifying transportation

• Low-carbon, sustainable biofuels to displace petroleum

• Carbon-capture and sequestration

• Converting waste streams to energy
Grids
Supergrids Are A Critical Technology

- Supergrids can connect remote sources of renewable power with locations of demand
  - It’s always windy and sunny somewhere

- Supergrids can connect remote large-scale storage
  - with locations of demand
  - with sources of intermittent renewable power

- Supergrids can create a global market for electricity
Supergrids Can Connect Remote Large-Scale Storage With Locations of Demand

• The European Example:
  – connect Norway to a European supergrid
  – Norwegian reservoirs and hydro plants could fill a continental gap in wind for up to four weeks
  – Not feasible with long-distance AC, feasible with DC
  – enables wind to supply up to 30% of demand
    • wind moves from irritant to base-load
  – Norwegian companies already building high-voltage DC grids between Norway/Netherlands/Germany

• Plans exist to build a grid from offshore Irish wind farms to customers throughout northern Europe
Supergrids Can Create a Global Market for Electricity

• We have a global market for oil
  – increases reliability
  – unclear whether a global market leads to higher or lower prices for oil

• We have a growing global market for natural gas

• Why not a global market for electricity?
  – Use high-voltage DC lines to bring solar energy to market from the Sahara, or wind and geothermal power South America and Siberia
Energy Storage
Energy Storage Is a Critical Technology

• Small-scale energy storage enables electrified transportation

• Large-scale energy storage enables greater use of intermittent domestic renewables (wind & solar)
Small Scale Energy Storage Enables Electrified Transportation

- Electrified transportation can use abundant domestic resources
  - including renewable sources such as wind and solar

- It is easier to minimize/mitigate the environmental impact of ~1500 power plants rather than 200+ million autos

- Key parameters that determine deployability
  - gravimetric density (energy storage per unit mass)
  - volumetric density (energy storage per unit volume)
Large Scale Energy Storage Enables Greater Use of Intermittent Renewable Sources

• Intermittency is the limiting factor for domestic renewable sources such as wind and solar

• Key parameters that determine deployability
  – Volumetric density (energy storage per unit volume)
  – Total volume or total capacity
Advanced Biofuels
Advanced Biofuels Are A Critical Barrier to Overcome

• Domestically produced
• Lower CO₂ emissions
• Are abundant
• Next-Generation biofuels
  – Algae
  – Cellulosic feedstocks
Carbon Capture and Storage
Carbon Capture and Storage is a Critical Technology

• CCS Enables the use of domestic solid fuels to make electricity and liquid fuels
  – coal and oil shale

• Key questions
  – What is the best capture method:
    • post-combustion: stripping, algae,…
    • pre-combustion: IGCC,…
  – What is the best sequestration method:
    • geological, ocean,…
    • embedded in products,…
Turning Waste Streams Into Energy Is An Untapped Opportunity
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- Waste Water
- Agricultural Waste
- Municipal Solid Waste
- Unrecycled Plastics
- Food Waste
Harvesting Waste Heat is the Biggest Untapped Opportunity

Estimated U.S. Energy Use in 2010: ~98.0 Quads

Source: LLNL 2011. Data is based on DOE/EIA-0384(2010), October 2011. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for hydro, wind, solar and geothermal in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." (see EIA report for explanation of change to geothermal in 2010). The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527
Don’t Bet the House on Technological Breakthroughs
Despite Advances, We Still Depend on 4 Fuels and 4 Technologies For Most of Our Activity
The American Love Affair With Technology
Americans Believe Technology Will Save the Day

“…there is excessive confidence in the potential of particular technical fixes that are seen to hold (often near-magical) solutions to our problems and whose early commercialization is forecast to bring prosperous future.”

Vaclav Smil, “Energy at the Crossroads”
Technologies Aren’t As Cheap As We Think

• “The Risk of Surprise in Energy Technology Costs”

• After extensive review of the literature and historical record, the paper concludes that:
  – future technologies will take longer to deploy than we think
  – future technologies will cost more than we think
  – overconfidence in cost & timeline forecasts hampers progress
Some Words of Caution About Technological Silver Bullets

• Breakthroughs in energy are rare: last two occurred during WWII
  – Catalytic cracking (enabled Texas oil to defeat the Axis powers)
  – Manhattan Project: was a substantial fraction of overall R&D and GDP
  – Rapid progress is possible with massive investment

• Tricks of the trade: comparing the best of optimistic future technologies against the worst of today’s technologies…
  – Technology improves ~1% per year….
    • don’t disregard incremental gains

• Technology solutions are more expensive than expected…

• No silver bullets…need a suite of solutions
Don’t Bet the House on Technological Breakthroughs
Michael E. Webber, Ph.D.

Associate Professor, Mechanical Engineering

Co-Director, Clean Energy Incubator

Associate Director, Center for International Energy & Environmental Policy

webber@mail.utexas.edu

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