The Future of Energy

(or: the race to get to 5 cents per kWh)

Moshe Kam
IEEE President-Elect
April 2010

Philadelphia PA
Regions 1-2 Students Activities Conference

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(or: the race to get to 5 cents per kWh)

"It is difficult to make predictions, especially about the future"

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- This presentation compiles information from various public sources and does not represent original research
- A list of principal sources is provided at the end of the presentation
- Direct quotes, ideas and figures were taken from articles published by the Economist, the International Energy Agency, and Wikipedia
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Why did I decide to speak about energy?

- **Because some of you asked me to…**
  - **frankly this is much more exciting than reviewing the organizational chart of IEEE**

Why did I decide to speak about energy?

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Why did I decide to speak about energy?

- Because the future of energy poses **important technical and societal challenges**
  - …which electrical and computer engineers will be called to solve
- Probably the next "boom" – a lot of wealth is at stake
- The future of energy is **a key focus of IEEE**
  - And a reason why IEEE exists

The future of energy is a new open front for us

- One of the most thrilling open fronts for electrical and computer engineers in the next 30-60 years

Some of the technological motivators for previous economical “booms”

- Coal-fired steam power
- Oil-fired internal combustion engines
- The DC Motor
- The rise of electricity
- The telephone
- Modern flight

- 1980: Computing
- 1990: Internet
- 2000: Biotechnology and Nanotechnology (not quite)

Some of the technological motivators for previous economical “booms”

Energy related

- **Coal-fired steam power**
- **Oil-fired internal combustion engines**
- The DC Motor
- **The rise of electricity**
- The telephone
- Modern flight

- 1980: Computing
- 1990: Internet
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In the last few decades the energy front was quiet:

- Coal has been cheap
- Natural gas has been cheap
- The 1970s aside, oil has been cheap
- Nuclear power went off the rails

- The pressure to innovate has been minimal

Recent changes may set us up for a new boom…

- **Oil is no longer cheap**
  - …and not just for political reasons as in the 1970s
  - World's production is growing sluggishly, demand is growing faster
    - Only Saudi Arabia and UAE are thought to be able to increase production
  - Mismatch between available oil and refinery capabilities
  - Natural gas prices went up with the price of oil
- **Questions about the supply of oil linger**
  - New sources of oil will be exploited, but prices will be higher (Deep water, Arctic; Tar Sands, Liquefied Coal)
- **Most importantly, alternative technologies have improved significantly since the 1970s**

“The Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil”

– Ahmed Zaki Yamani

(Organization of the Petroleum Exporting Countries)

Additional observations…

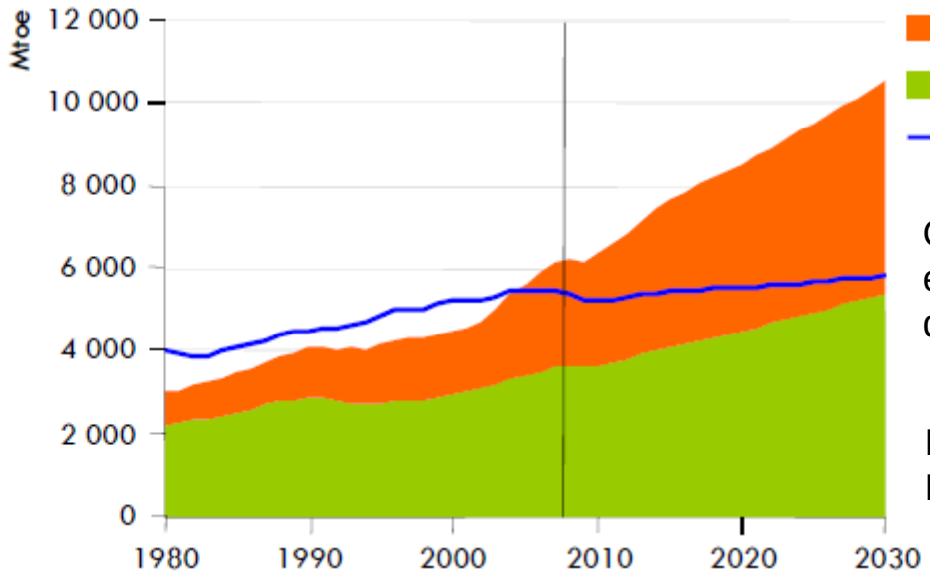
- **Coal remains cheap**
  - But many corporations are reluctant to build coal fired power plants
    - Resistance to pollution
    - Fear of Carbon Dioxide taxes

- **We are not going to conserve our way out of this problem**
  - Efficiency improvements will help but will not provide a comprehensive solution

- **Price, political pressure and environmental considerations appear to push in the same direction**

World primary energy demand in the Reference Scenario

World Energy Outlook 2009



OECD= Organization of economic cooperation and development

Mtoe = Million Tons of Oil Equivalent

Non-OECD countries account for 93% of the increase in global demand between 2007 & 2030, driven largely by China & India

Source: IEA

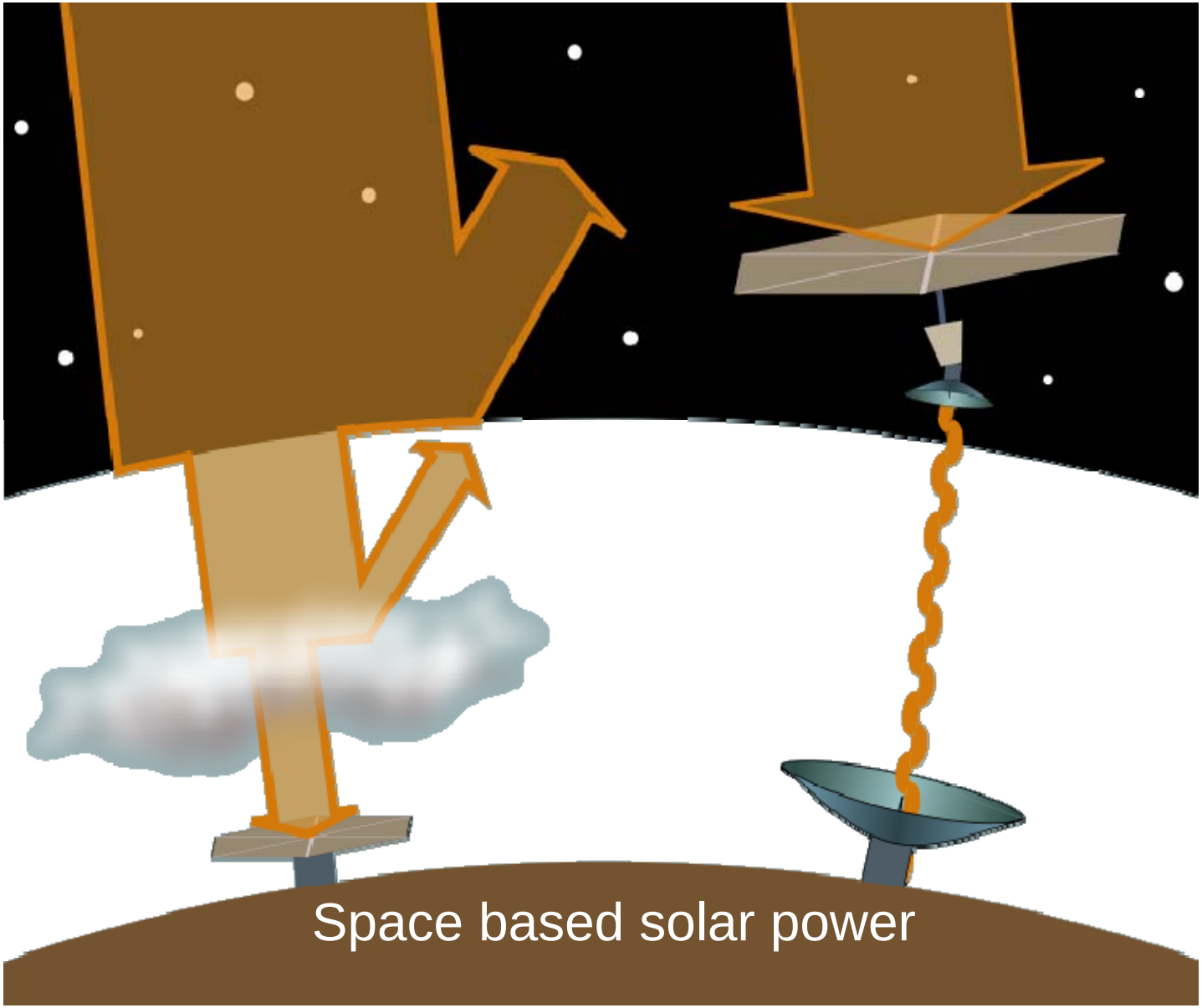
Alternatives under consideration…

- Wind Power
- Carbon Storage
- Solar Energy
- Geothermal Generation
- Biofuels
- Nuclear Energy's return
- Wave Power
- Tomorrow's cars

- Moreover we may be moving to systems that generate energy **locally**
  - As we did a century ago
  - Solar cells, wind turbines

Alternatives that do not appear promising at the moment…

- Nuclear Fusion
- Space based solar power
  - Giant satellites collecting energy and beaming it to earth
- Floating platforms that capture wave energy
- Tidal power
- Energy-storing Ultra-capacitors
- The hydrogen economy, fuel cells



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How large is the energy market?

- Present world population consumes about **15 terawatts of power**
  - A terawatt = 1,000 gigawatts
  - gigawatt = capacity of the largest sort of coal-fired power station

- By 2050, power consumption is likely to have risen to **30 terawatts**

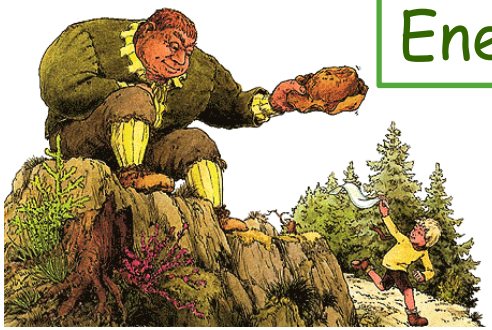
Economical Impact

- The Energy business is worth

  $6 trillion a year

  – about a tenth of the world's economic output

- Compare to information technology, a market measured in mere hundreds of billions

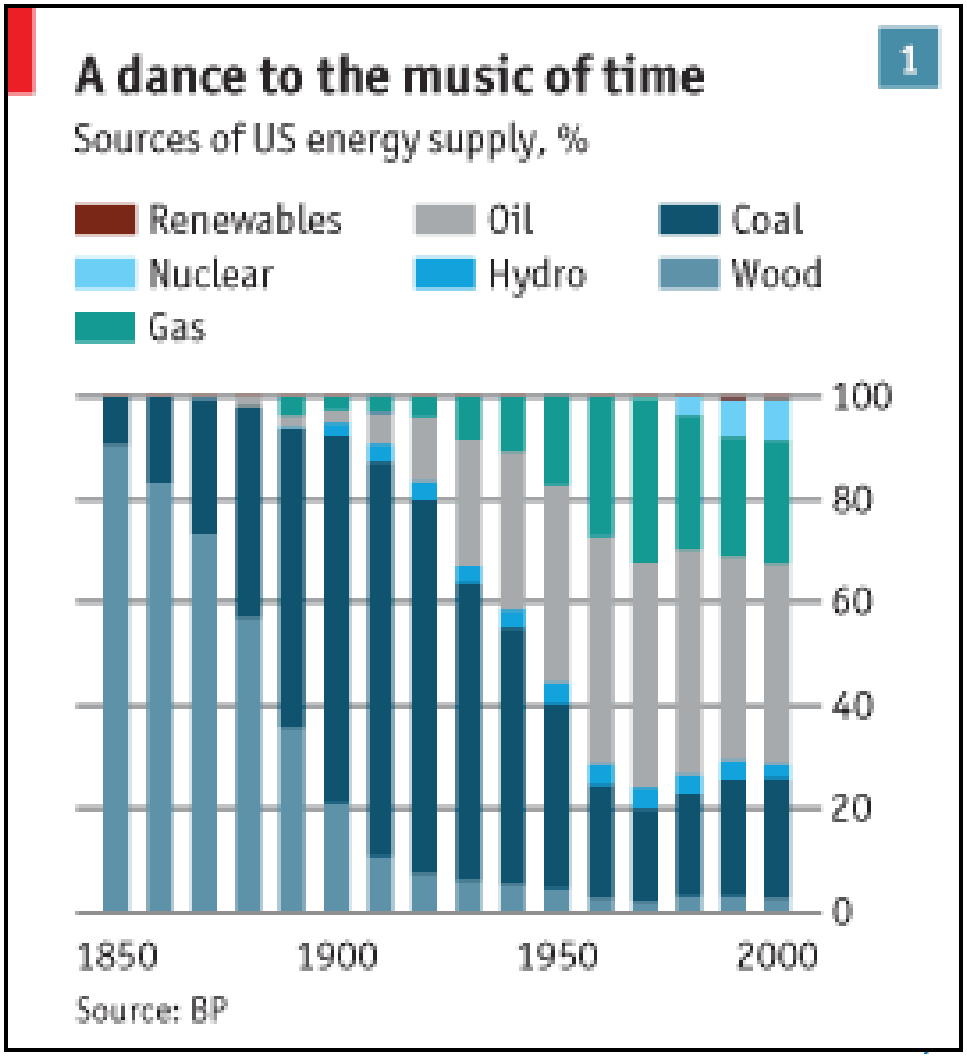


Energy

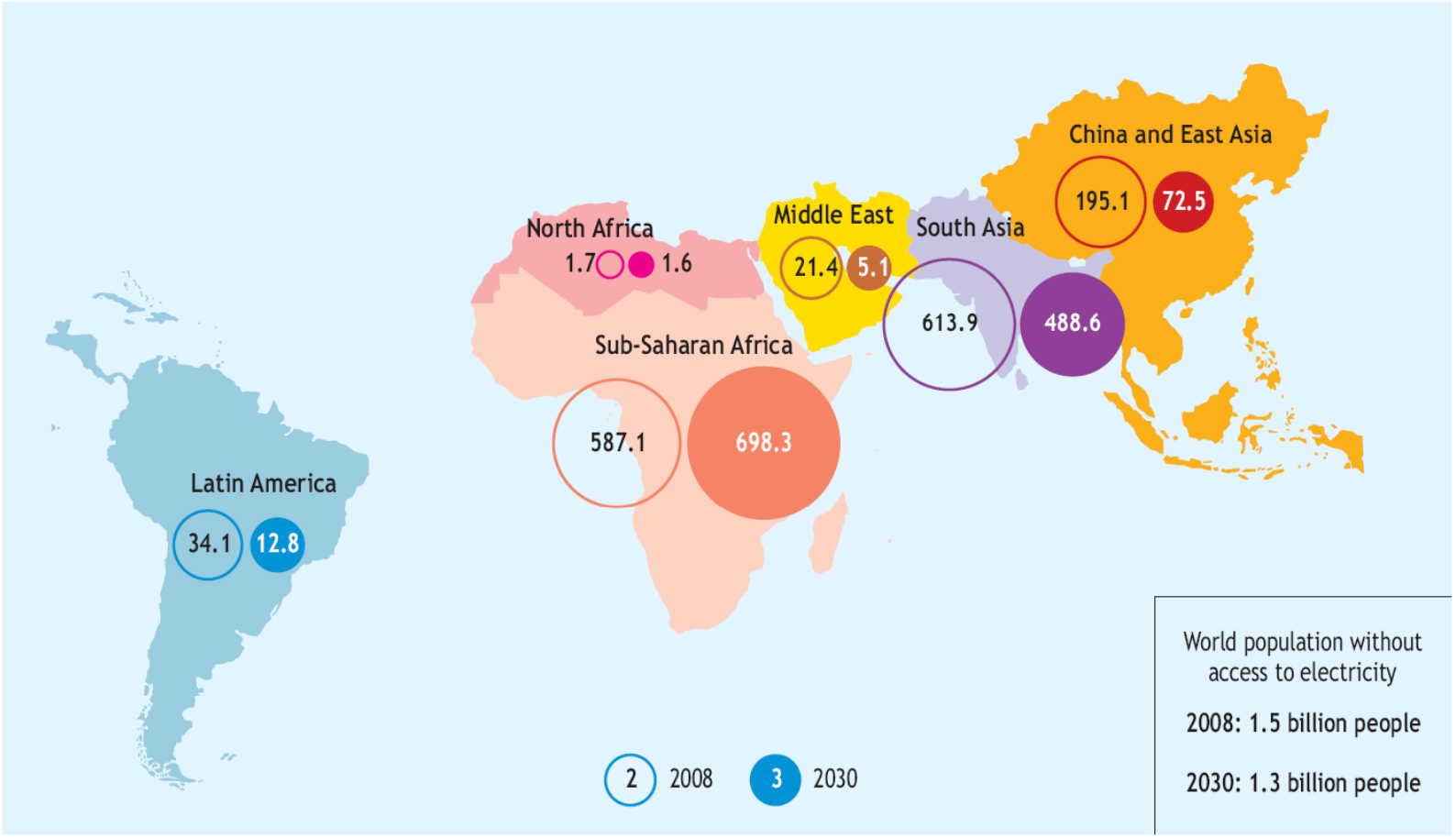
Information Technology

How will the market move…
…if the past is indicative of the future, it will be slow…

Or… we may experience **disruptive technology** (say when our cars quickly plug into electricity sockets)



And lest we forget: number of people without access to electricity (in millions)



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Source: IEA

"Yes, but renewable energy is heavily subsidized"

- A common argument against new sources of energy
- Ignores the fact that existing energy conglomerates also receive large public subsidies
  - And they often do not pay for the environmental damage they inflict
- One estimate: US oil companies receive preferential treatment from the government worth more than $250 billion a year

More on subsidies…

- Still… not all subsidies are equally justified:
  - Subsidies in Germany for solar energy
  - Subsidies in the US for maize-based ethanol farmers

- Perhaps the best public policy is **appropriate tax on Carbon**…
  - If enacted, would make wind-based electricity competitive with energy based on fossil fuels overnight

Meanwhile… away from the rich world

- China continues to build coal fired power stations
  - But it also has a large wind-based production
  - China is the second largest manufacturer of solar panels
  - Largest number of solar-heated rooftop hot-water systems in the world
- Brazil has the second largest bio fuel industry
  - 40% of fuels consumed by cars
  - 15% of electricity

Solar Energy

Photo-voltaics: Solar Energy ⟶ Electricity

The Growing Pains of Solar Energy

- Power from photovoltaic systems (solar cells) costs $200-600 a megawatt-hour
  - Depending on the efficiency of the installation and the discount rate applied to future output
- Onshore wind power in America: $50-70 per MWh
- Even lower prices for power from fossil fuels
  - unless taxes on greenhouse-gas emissions are included
- ***At present there would be no significant market for solar cells if there were no government subsidies***

International Energy Agency

Where is current demand?

- Germany
  - Half of the world's demand
  - Due to government subsidies
  - Due also to fall of panel prices

- In the past, Spain
  - 2GW installed due to government subsidies in 2007

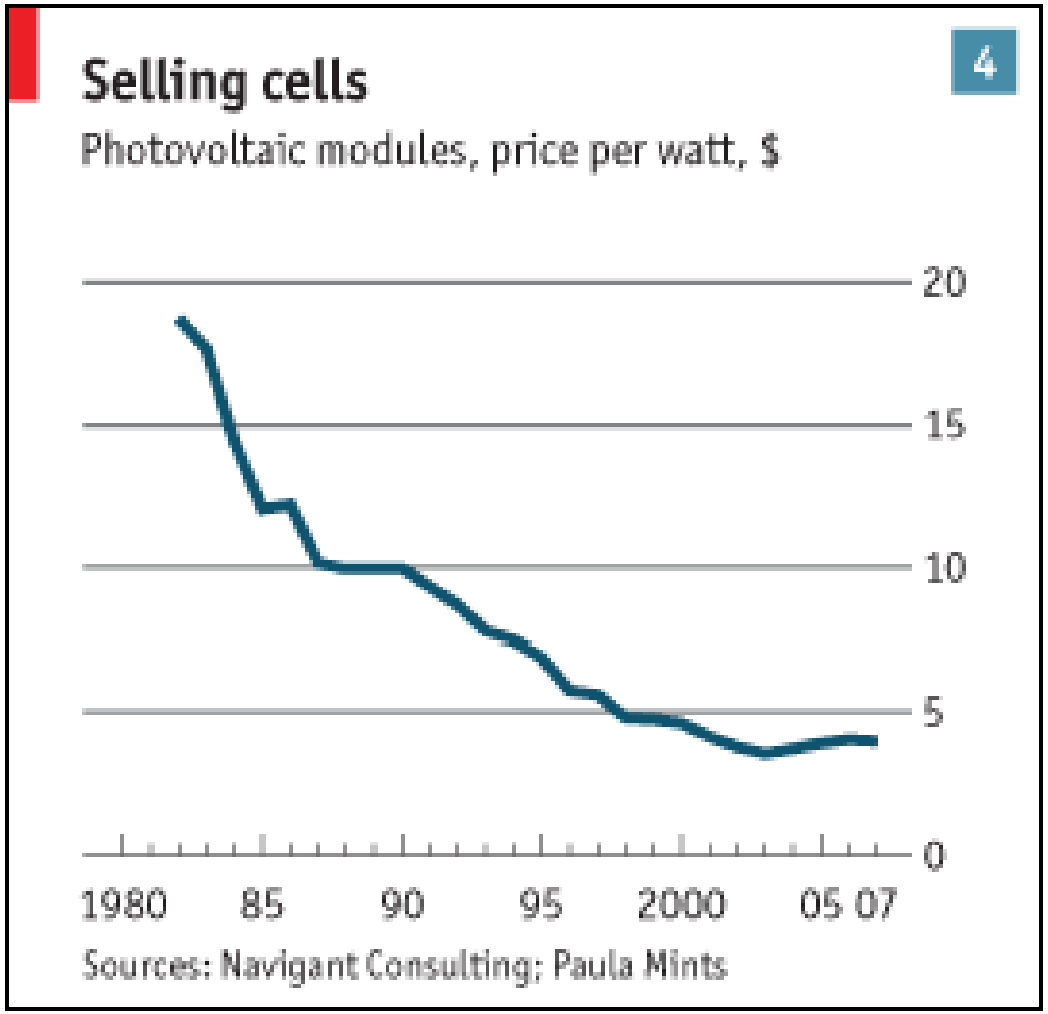
- Total new demand in 2006: 1.7 GW
- Total new demand in 2010: 10.5 GW

Solar cells are becoming cheaper

- Half of the world's production capacity is already in China
  - China's share is expected to grow

NEW TECHNOLOGIES

- Thin film cells that use less Silicon
  - Less efficient; more suitable for sunny desert areas
- Cells that use no Silicon
  - cadmium telluride (China's *First Solar*)
    - cost less than a dollar a watt to make
      - cheaper than any silicon-based rivals.
    - output is about a gigawatt a year


Selling cells
4
Photovoltaic modules, price per watt, $
20
15
10
5
0
1980
85
90
95
2000
05 07
Sources: Navigant Consulting; Paula Mints

…but photo-voltaics is still a very expensive business

- A typical solar cell utility-scale installation produces power at only one fifth of its maximum capacity
  - thanks to clouds, night-time, and dirty panels
- To replace a one-gigawatt coal plant running at 70% of capacity with solar panels would require about half of the 6GW installed worldwide last year

Possible alternative; solar thermal (solar energy into heat)

- Use mirrors to concentrate heat, produce steam and drive turbines
- Low temperature collectors: flat plates generally used to heat swimming pools
- Medium-temperature collectors: flat plates used for creating hot water for residential and commercial use
- High temperature collectors: concentrate sunlight using mirrors or lenses and are used for electric power production

Only 600 megawatts of solar thermal power is up and running worldwide in October 2009

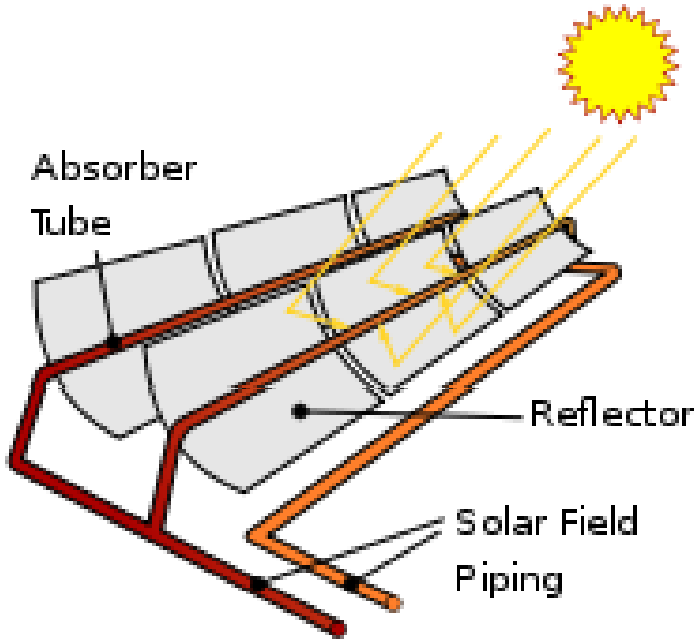
Solar Panels for Heating Water

The Solar Bowl above a Solar Kitchen in Auroville, India concentrates sunlight on a movable receiver to produce steam for cooking

- A fixed spherical reflector with a receiver which tracks the focus of light as the Sun moves across the sky
- Receiver reaches temperature of 150 ° C
- Produces steam that helps cook 2,000 daily meals

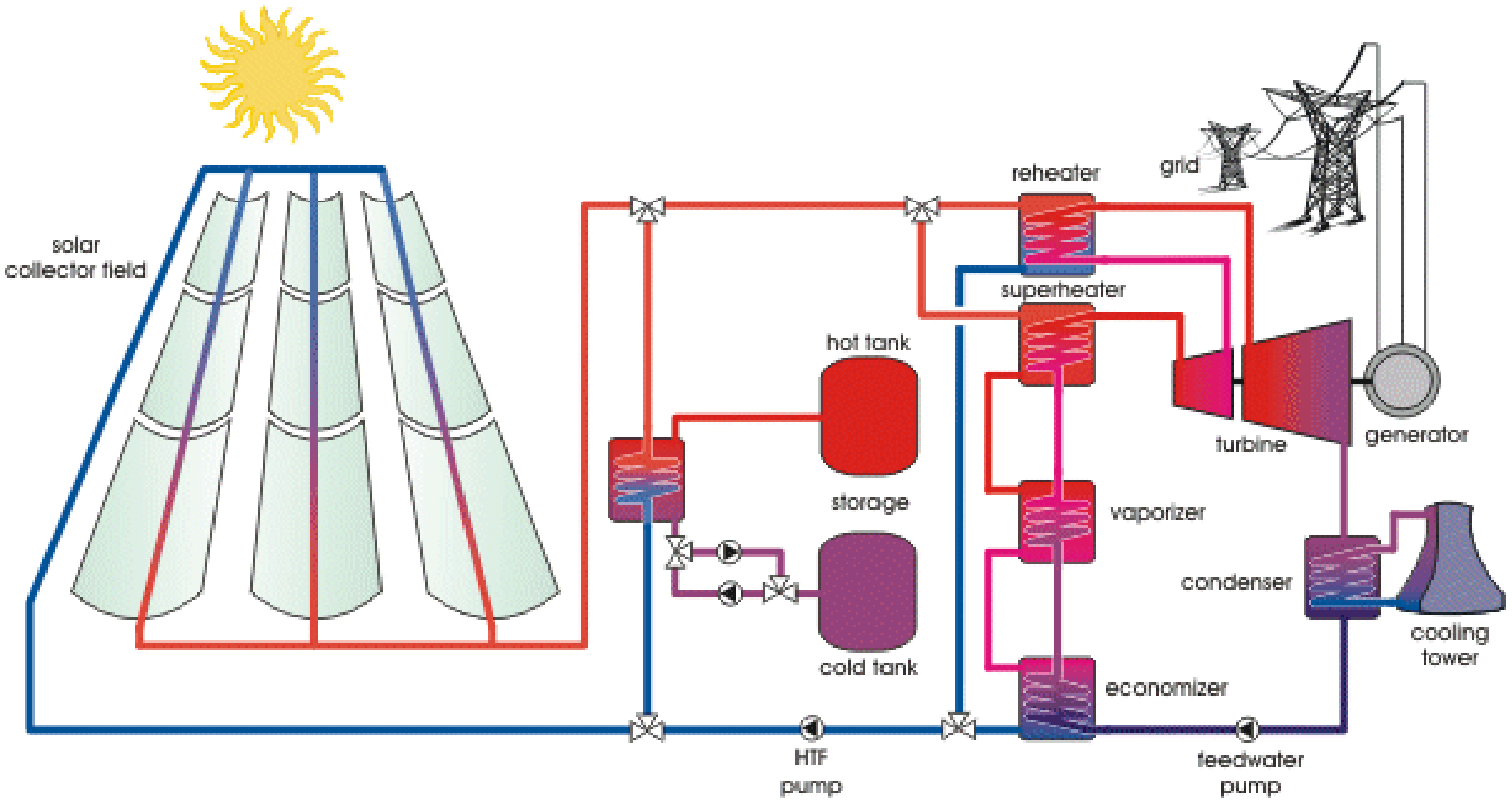
The solar furnace at Odeillo in the French Pyrenees-Orientales can reach temperatures up to 3,800 degrees Celsius

A Parabolic Trough Design



Curved, mirrored trough which reflects the direct solar radiation onto a glass tube containing a fluid running the length of the trough, positioned at the focal point of the reflectors

A change of position of the sun parallel to the receiver does not require adjustment of the mirrors


solar
collector field
reheater
grid
superheater
hot tank
turbine
generator
storage
vaporizer
condenser
cooling
tower
cold tank
economizer
HTF
pump
feedwater
pump

A Power Tower

- A tower that receives focused sunlight
- It uses an array of flat, movable mirrors (called heliostats) to focus the sun's rays upon a collector tower (the target)

Other designs

The Future of Solar Thermal Power Generation

- **Efficient solar-thermal plants can be built on the same sort of scale as gas-fired power stations**
  - **a few hundred megawatts at a time**
- **Harder to finance and plan than small photovoltaic installations**
- **A *Brightsource Energy* project in the Mojave desert is planned to deliver more power than all the photovoltaic cells installed in America last year**

Venues for Solar Thermal Plants

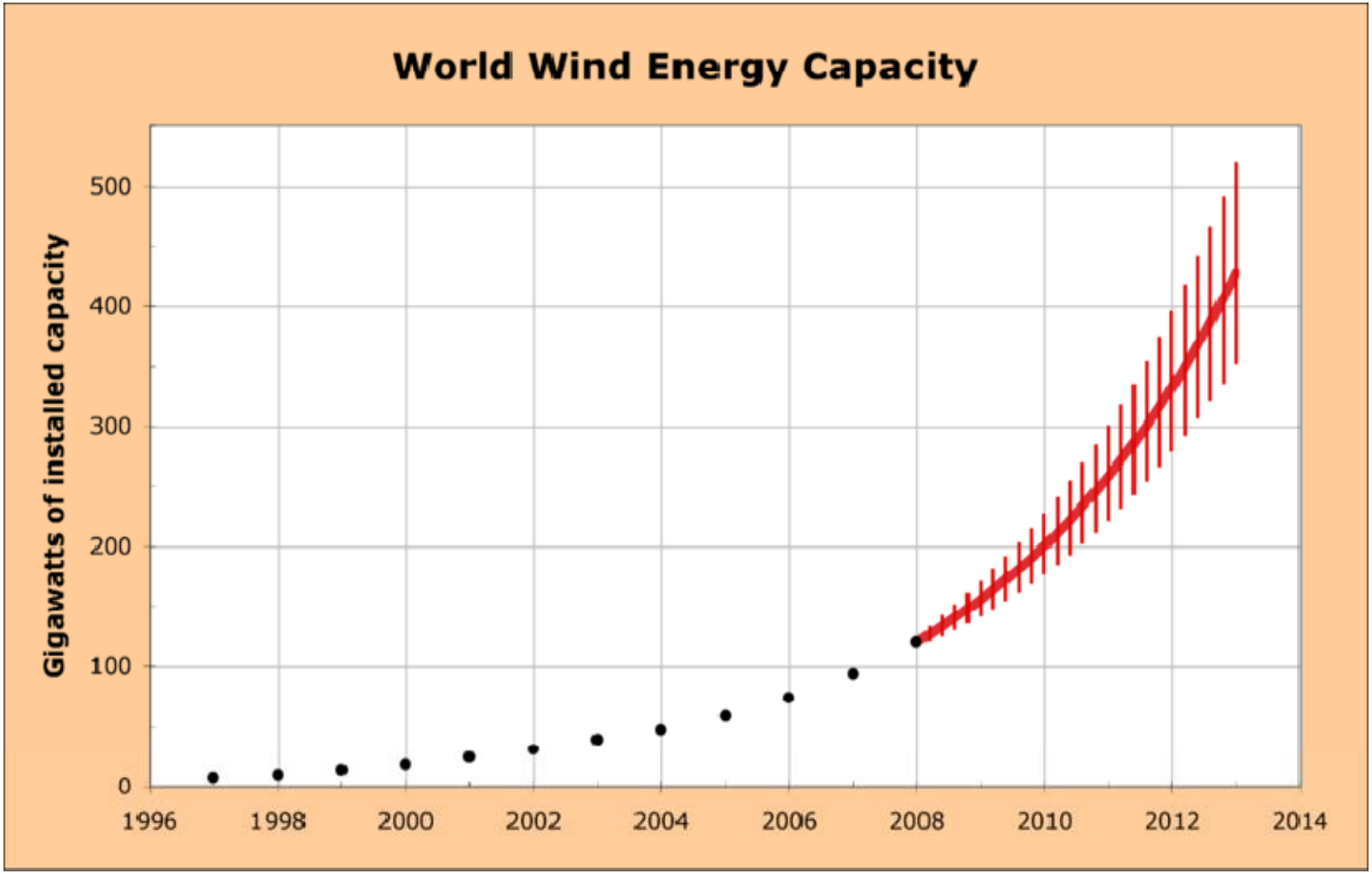
- **200 gigawatts-worth of prime sites for solar-thermal power in Western USA**
  - places that have enough reliable sunshine
  - are close to transmission lines
  - are not environmentally or politically sensitive

- This is equivalent to 20% of America's existing electricity-generation capacity

Wind Power

Wind Power

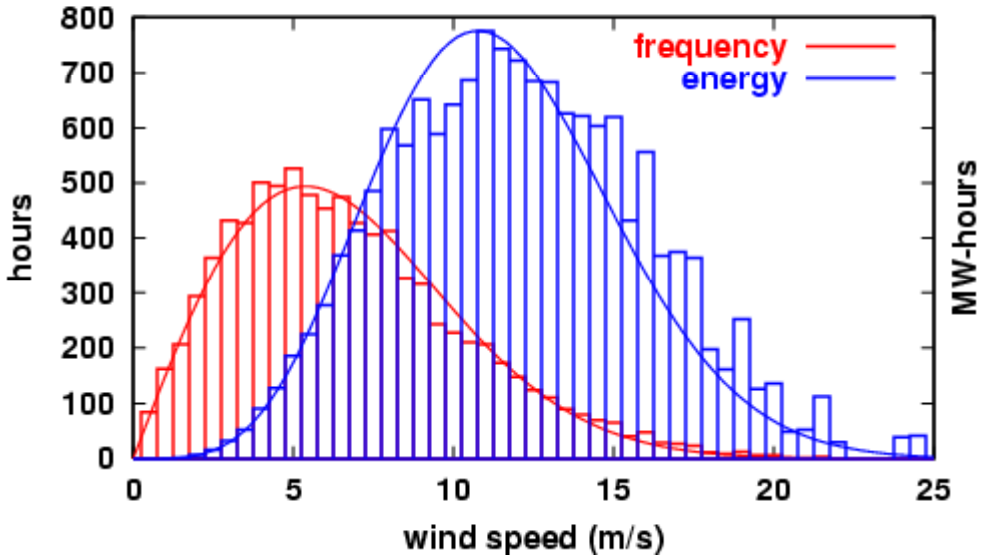
- World capacity is growing at 30% a year
- Will exceed 100 gigawatts this year
- By 2012 close to half of the *new* generating capacity built in America will be wind-powered
  - Currently only 1% of US energy comes from wind
  - 15% by 2020
- Price for kWh is 8 cents (compared to 5 cents from coal power)
- Wind farms can be built piecemeal



Technological progress

- The first turbines were cobbled together from components intended for ships
- Now we are borrowing from aircraft design
  - composite materials
  - variable-geometry blades
    - make blades as long as possible
    - “bigger is better” with turbine technology
- Better meteorological forecasting allows better prediction of supply

Modeling



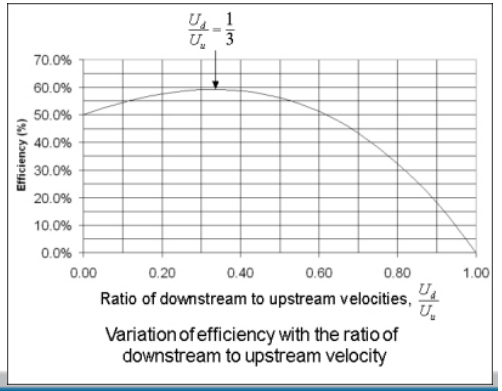
Distribution of wind speed (red) and energy generated (blue) for all of 2002 at the Lee Ranch facility in Colorado. The histogram shows measured data, while the curve is the Raleigh model distribution for the same average wind speed. Energy is the Betz limit through a 100 meter diameter circle facing directly into the wind. Total energy for the year through that circle was 15.4 gigawatt-hours

Smart Blades

- A blade that can flex and “spill” part of the wind when the wind blows too strongly
  - able to turn when other, lesser turbines would have to be shut down for their own safety
- Reliability improvements
  - Downtime has gone down from 15% to 3% in a decade

Efficiency

- The theoretical maximum efficiency of a turbine, worked out in the early 20th century by Albert Betz, is 59.3%
- Modern turbines get surprisingly close to that, being about 50% efficient.



Variation of efficiency with the ratio of downstream to upstream velocity

The modern three bladed wind turbine

- Pointed into the wind by computer-controlled motors
- High tip speeds of over 320 km/h, high efficiency, and low torque ripple
- Blades are usually colored light gray to blend in with the clouds
  - range in length from 20 to 40 meters.
- The tubular steel towers range from 60 to 90 meters tall.
- The blades rotate at 10-22 revolutions per minute
  - At 22 rotations per minute the tip speed exceeds 300 ft per second

Turbines

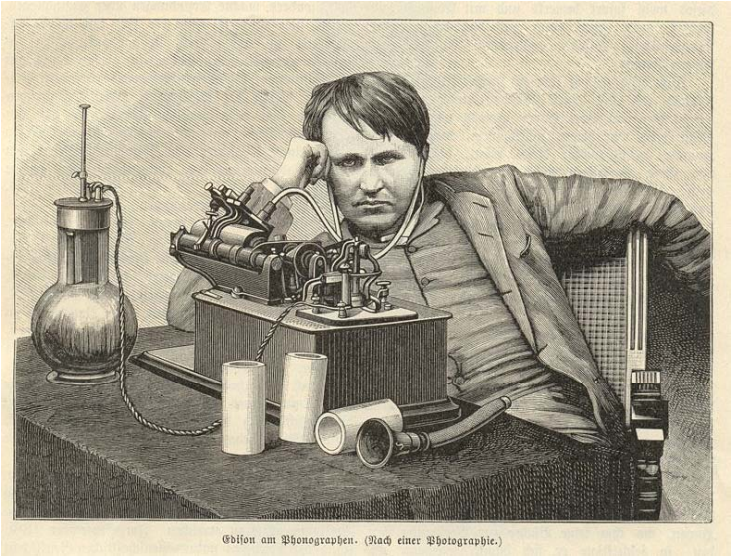
- A gear box is commonly used to step up the speed of the generator
  - although designs may also use direct drive of an annular generator
- Some models operate at constant speed, but more energy can be collected by variable-speed turbines which use a solid-state power converter to interface to the transmission system.
- Shut-down features to avoid damage at high wind speeds

Biggest drawback: location

- People tend not to live where the best wind farms are located
- Electricity grids will have to become bigger and smarter
- The new grids *may* use DC (not AC)
  - DC better suited to transporting power over long distances
  - Less power is lost
  - DC cables can be laid on the seabed

Back to "the War of the Currents"?

“The War of the Currents”



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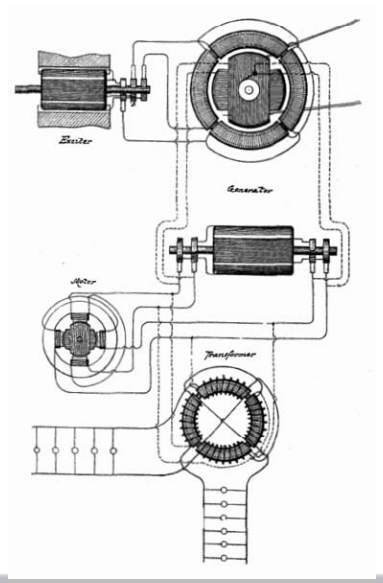

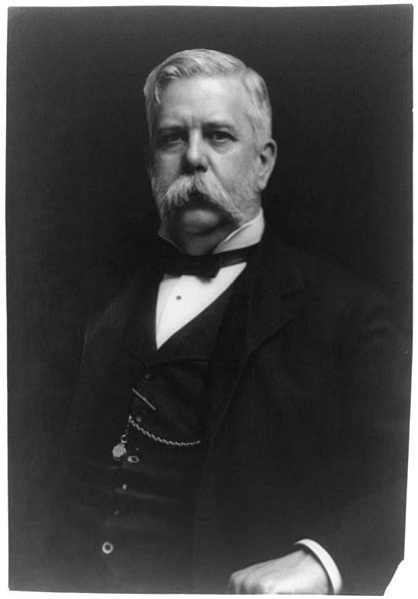

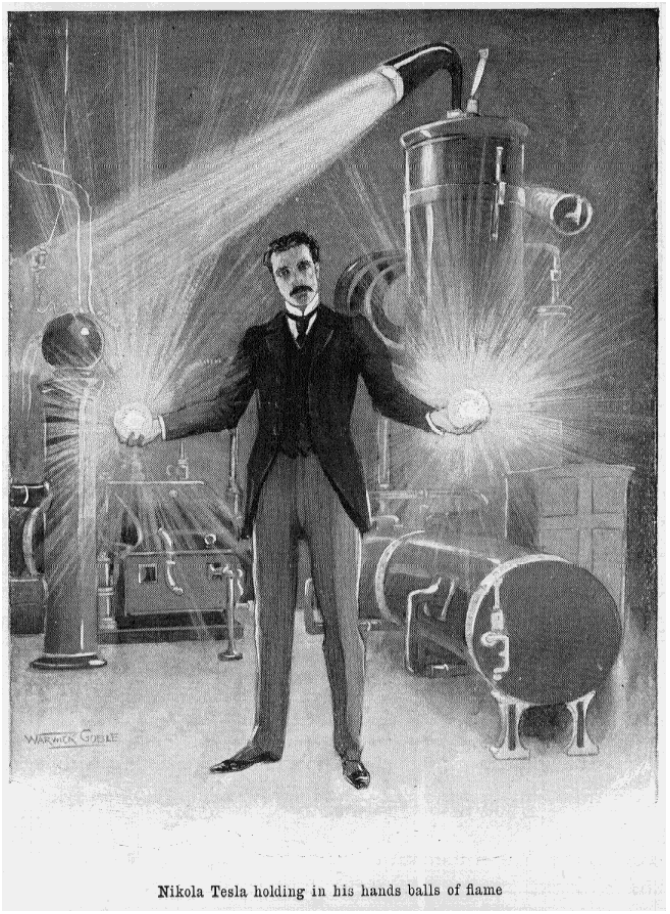

Nikola Tesla holding in his hands balls of flame

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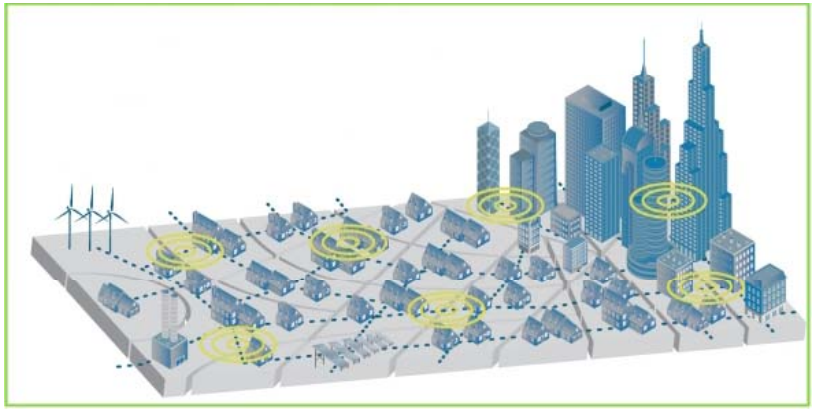
The Smart Grid

- A large-scale intelligent network for generation and distribution of power, using communication, sensing, actuation and control

- Smoothes spikes and evens supply and demand
  - Reduces spikes in demand, eliminates “peakers”

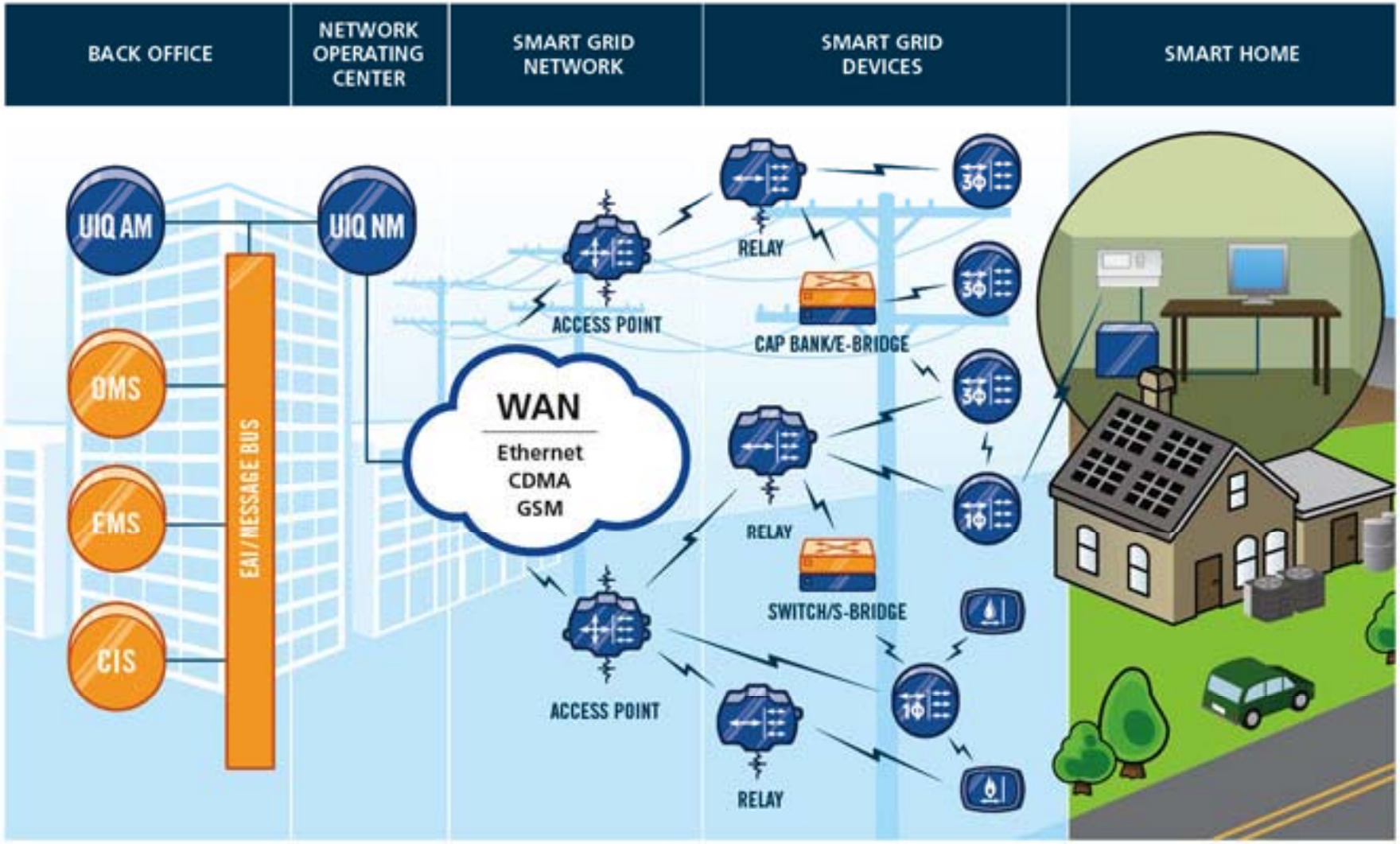
Monitoring and Control

- Monitors load and makes system-wide adjustments
  - For example takes some loads off the grid based on prior agreement
    - in exchange for lower price
  - Down to shutting off some appliances in a customer's house during peak demand hours



Functions of the Smart Grid

- Integration of generation sources
- Demand management
- Control of smart appliances
- Sensing, protection and isolation
- Disturbance rejection
- Prediction of supply and demand
- Storage



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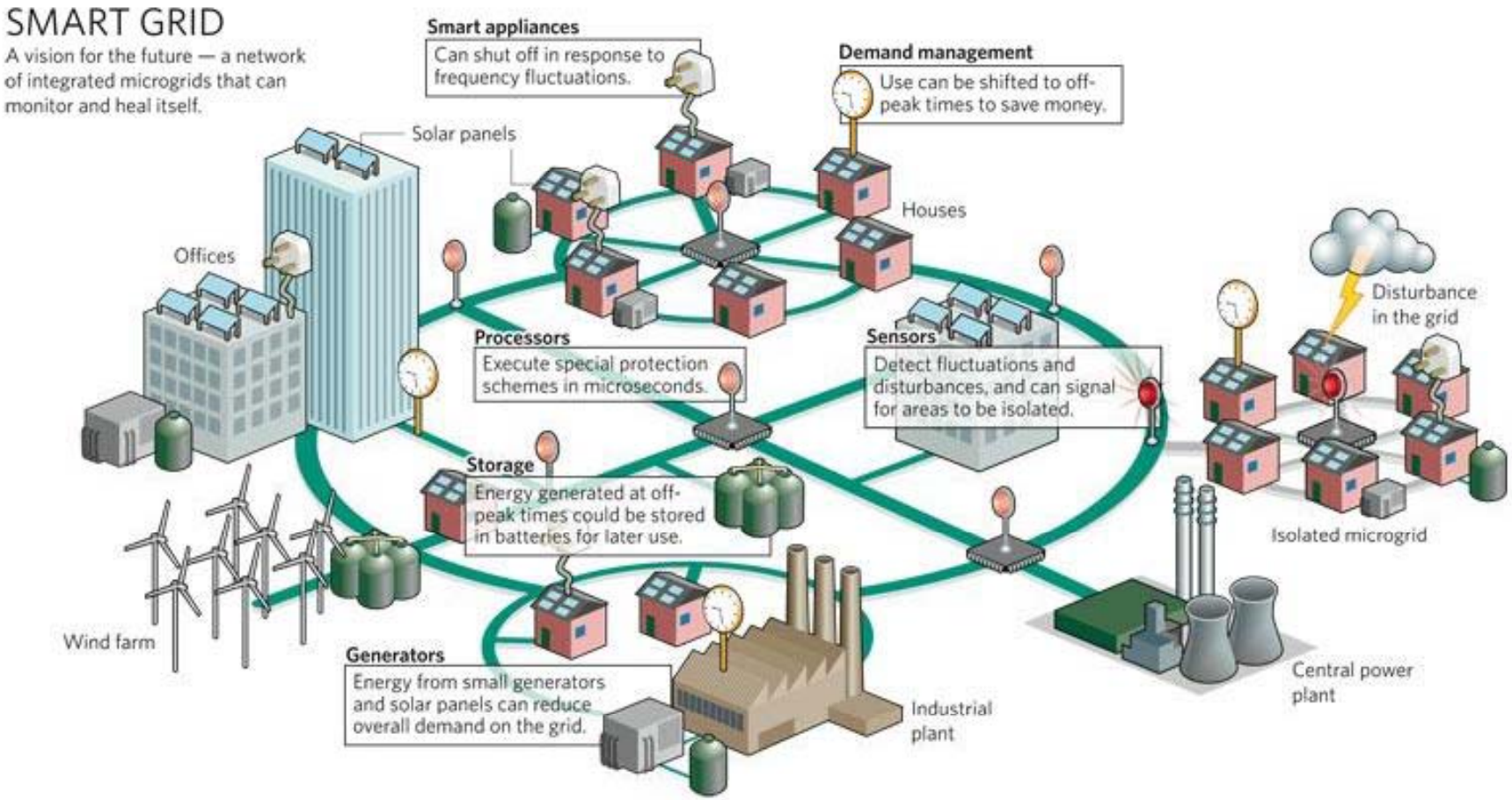
SMART GRID
A vision for the future — a network of integrated microgrids that can monitor and heal itself.
Smart appliances
Can shut off in response to frequency fluctuations.
Demand management
Use can be shifted to off-peak times to save money.
Solar panels
Houses
Offices
Disturbance in the grid
Processors
Execute special protection schemes in microseconds.
Sensors
Detect fluctuations and disturbances, and can signal for areas to be isolated.
Storage
Energy generated at off-peak times could be stored in batteries for later use.
Isolated microgrid
Wind farm
Generators
Energy from small generators and solar panels can reduce overall demand on the grid.
Industrial plant
Central power plant

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IEEE, the world's largest technical professional association, is at the forefront of the global smart grid initiative. **Learn More**

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IEEE Smart Grid News:

14 April 2010
Former Deputy Under Secretary of Defense Setting the To...

08 April 2010
IEEE SmartGridComm 2010

07 April 2010
Smart grid standards: Why are they needed and how will ...

05 April 2010
2010 IEEE International Reliability Physics Symposium (...

01 April 2010
Nearly $4 bil from DoE giving US Smart Grids a boost, f...

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21 APR IEEE/PES Transmission & Distribution Conference & Exposition /...

02 MAY 2010 IEEE International Reliability Physics Symposium (IRPS)

23 MAY IEEE International Conference on Communications

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Smart Grid Spotlight

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The smart grid's killer app: charging plug-in cars

- The smart grid will be able to regulate the charging of plug-in cars
  - *Due to battery limitations we are currently focusing on hybrids*
  - *No longer talk of fuel cells and hydrogen economy*

- Cars connected to the grid could also be usable as "micro-peakers"
  - source of energy when a large unexpected demand needs to be met

We do not know what would work…

- Electric cars or bio-fuels
- Breakthrough in CO_2 storage would bring Coal back into the picture
- Is geothermal energy better or worse than solar energy?

- **We do know however that the price of some alternatives (especially wind) is becoming competitive with Coal**

Closing words

- We have just peeked at the field

- The challenges and the rewards of contributing to the "future of energy" are huge
  - Though many new approaches will fail and many good ideas will not materialize

- The future of energy provides electrical engineers with new opportunities to innovate in a field which is…
  - Technically sophisticated and demanding
  - Of great social impact
  - Competitive
  - Offers high potential for economical rewards

Sources

- **The Economist**
  - Growing Pains (15 April 2010)
  - The Future of Energy (19 June 2008)
  - Double, double, oil and trouble (29 may 2008)

- www.iea.org
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