2015, Spring Semester

Energy Engineering (Class 458.624)

- Professor
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  - Classroom : 302-720
  - Class time : Monday, Wednesday 11:00 ~ 12:15

- Textbook

(1) Introduction to Solid State Physics (Charles Kittel)

(2) Solid State Electronic Devices (Ben G Streetman, Sanjay Kumar Benerjee)

CNN selected 2013 top 10 innovative ideas

Introduction

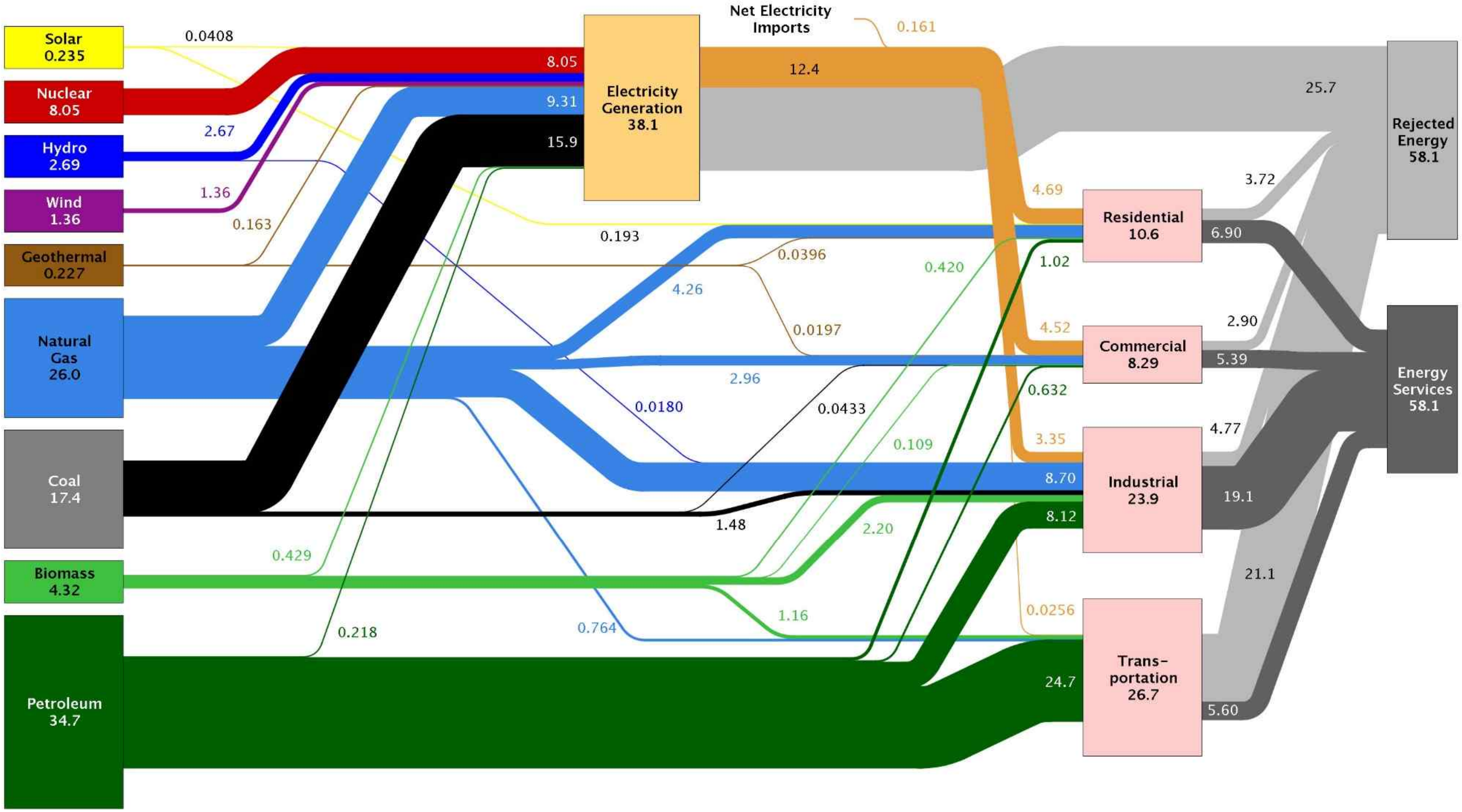
In this class, our interest is in the engineering of energy related devices.

We will start with fundamental concepts of solid state physics to study PN junction diodes that are mainly used for many optoelectronic energy devices (ex, PVs and LEDs). Then we will continue our study for energy storage devices (ex, SCs and Batteries).

As an introduction of the class, energy markets and hot research topics of energy engineering will be briefly reviewed.

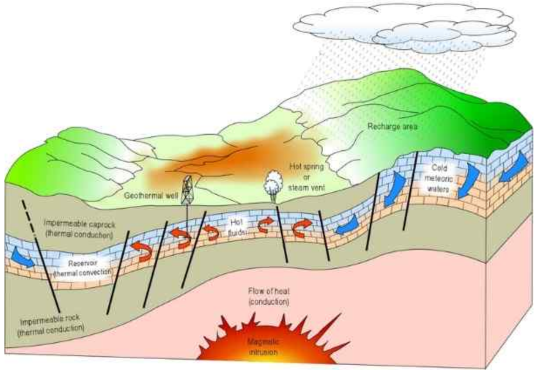
2012 US Energy Production

- Energy production still relies on oil (~35%), gas (~26%) and coal (~17%) (in total ~78%).
- Most of consumption is due to electricity generation (~38%) and transportation (~27%).
- Driving forces for new energy sources are "environmental issue (CO_2 emission)" and "oil price (fossil fuels are limited resources)".
- Power generation relying on nuclear reaction has risks of accidents (Fukushima disaster).
- Novel renewable, clean energy (eg. hydro, wind, geothermal, biomass, and solar) is required.



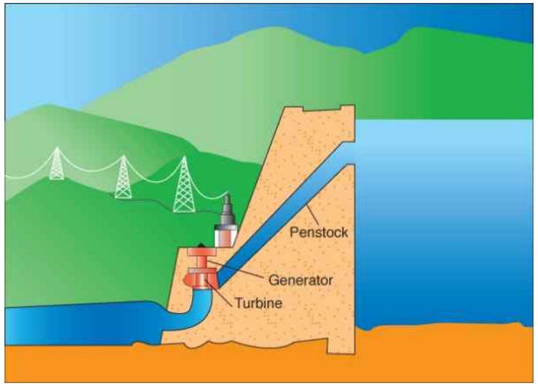
Geothermal Power

Magma rising from the mantles brings unusually hot material near the surface and heat from the magma is used for generating electricity.



Hydro Power

Right cartoon shows a cross-section of a typical hydroelectric dam. Water flows down the penstock, turns the turbine blades which power the electricity generators. There are concerns of environmental destruction.



Wind Power

In most places, the cost of commercial wind power on a large scale is not now economically competitive with conventionally generated electricity.

→ Large construction is required for above three cases

Biomass

Biomass energy is derived from organic matter. Stoves that burn wood are the classic example.

Biofuels differ from other renewable energy sources, such as wind, hydroelectric, geothermal and solar, as they are primarily used in the transportation sector and are derived from recently living matter, both plant and animal.

Some insists that biofuel is destructing forests and eventually causes damages to our environment.

Solar cells convert light into electricity.

The cost of current solar cells (poly Si) is high but is being reduced and the efficiency of cells is up to 23% and is continuously improving (GRID parity in some locations - Europe).

Solar panels are situated on roof of building →

In US, solar power generation facility is located in desert for high intensity and long sunlight hours.

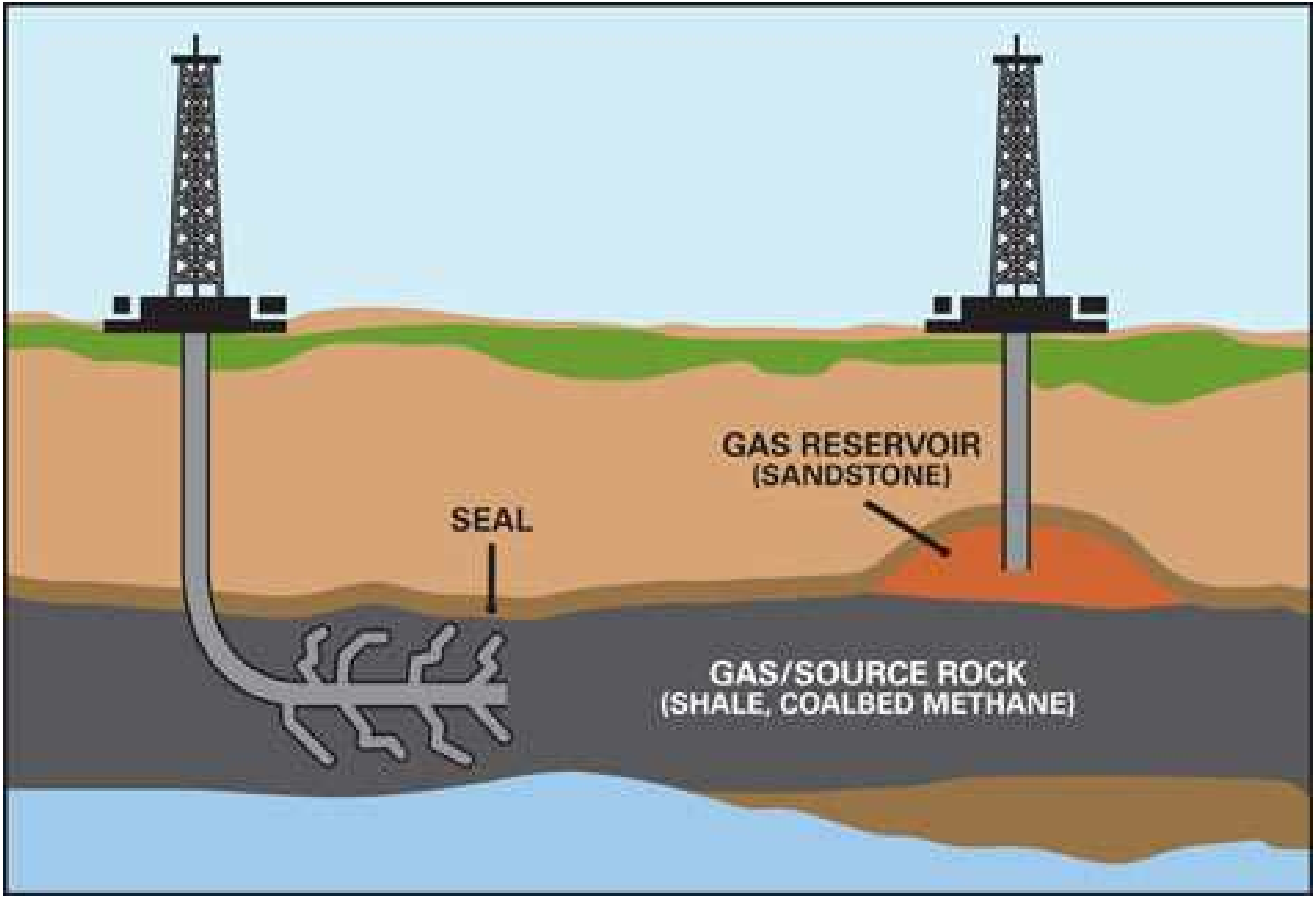
Solar energy is clean energy. It produces no hazardous solid, liquid or gas wastes.

They are used to power the space station (GaAs) and to provide electricity in remote areas on Earth (Africa, Mountain).

In summary, to make solar energy truly useful for large-scale power generation:

We need more efficient solar cells.

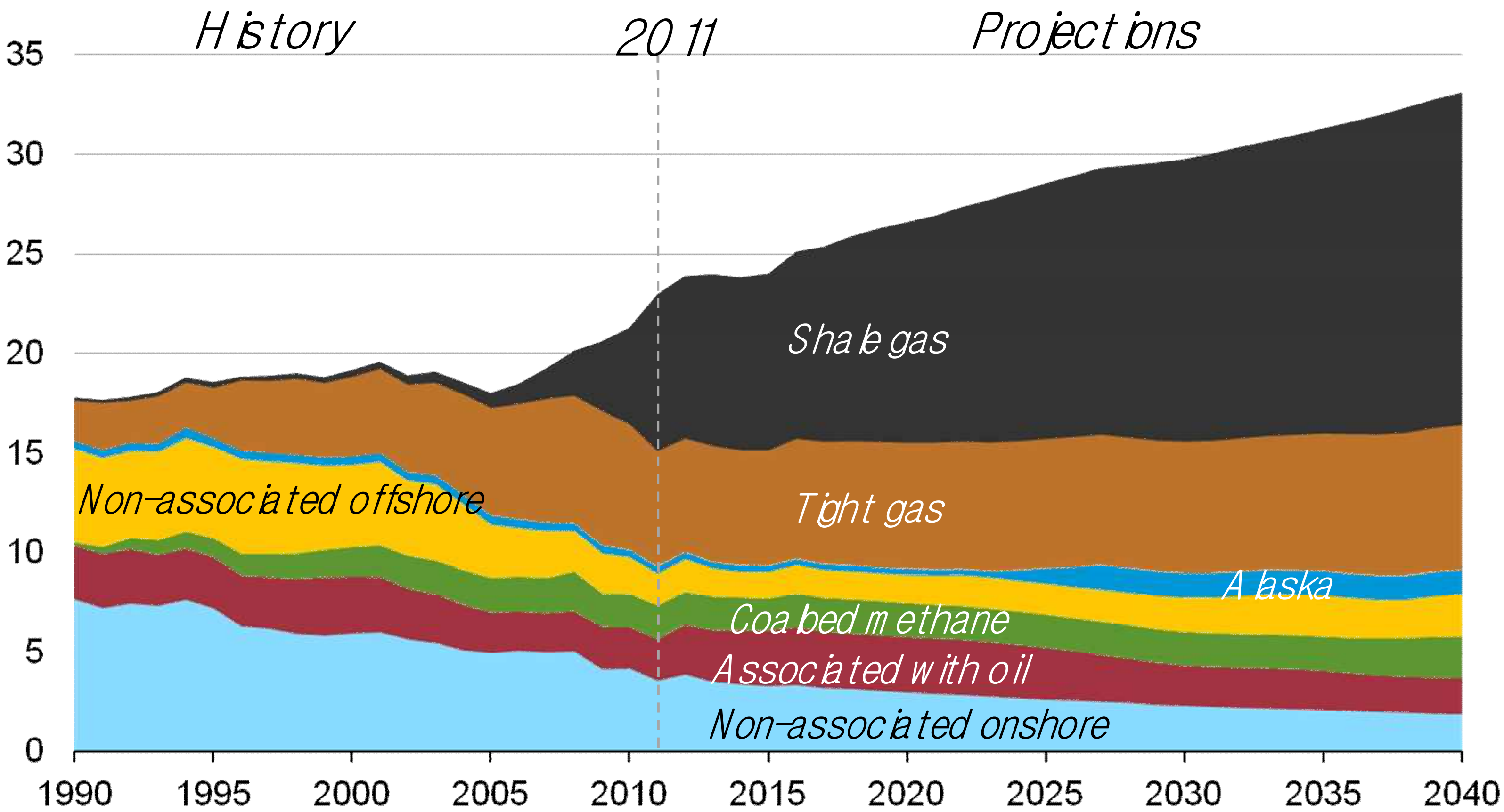
We also need better electricity storing devices.


GAS RESERVOIR
(SANDSTONE)
SEAL
GAS/SOURCE ROCK
(SHALE, COALBED METHANE)

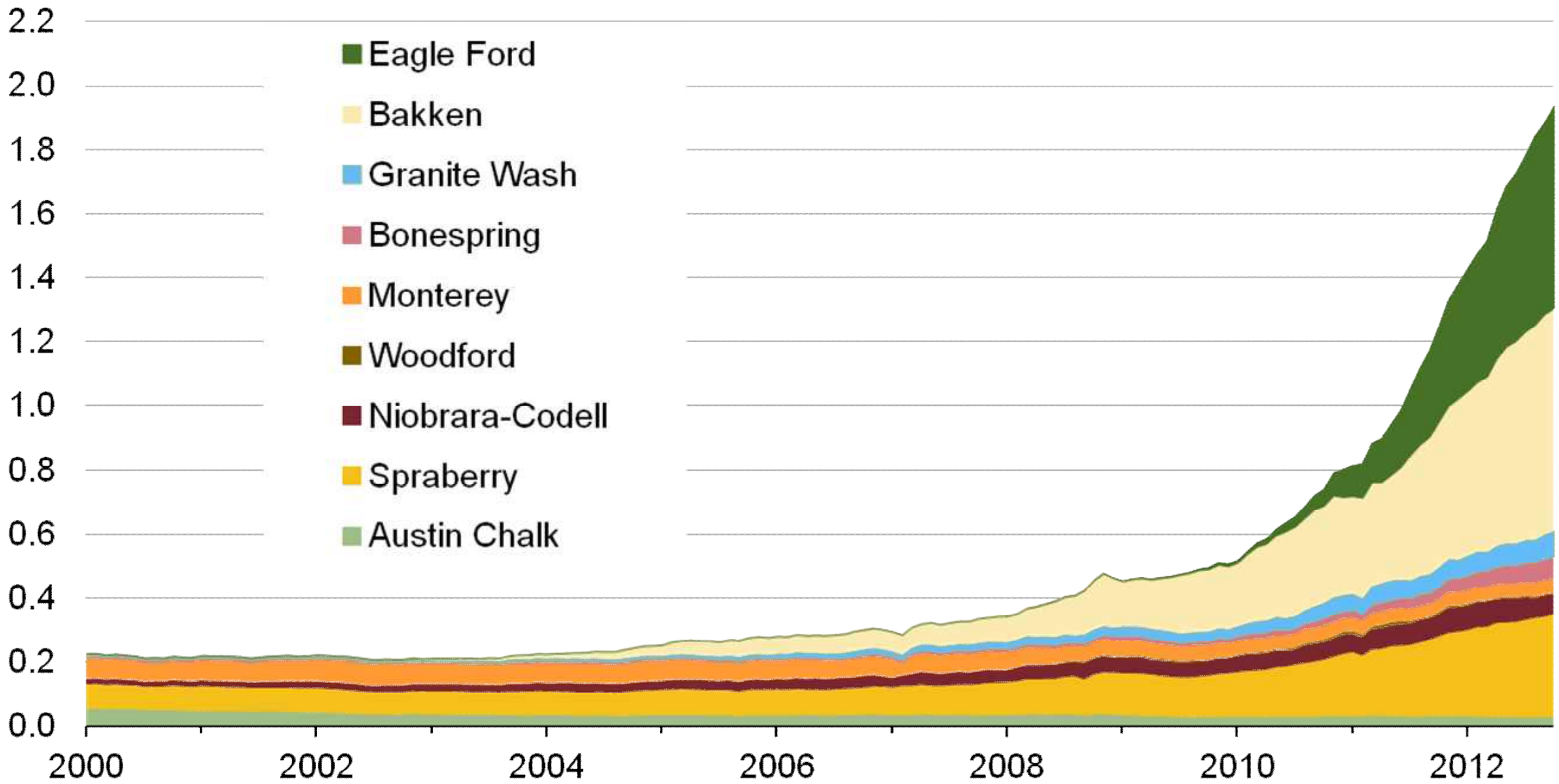
US Gas Production

Shale gas leads growth in total US gas production through 2040.

US gas price is decreasing and many energy-requiring industry (such as steel industry) is coming back to US.

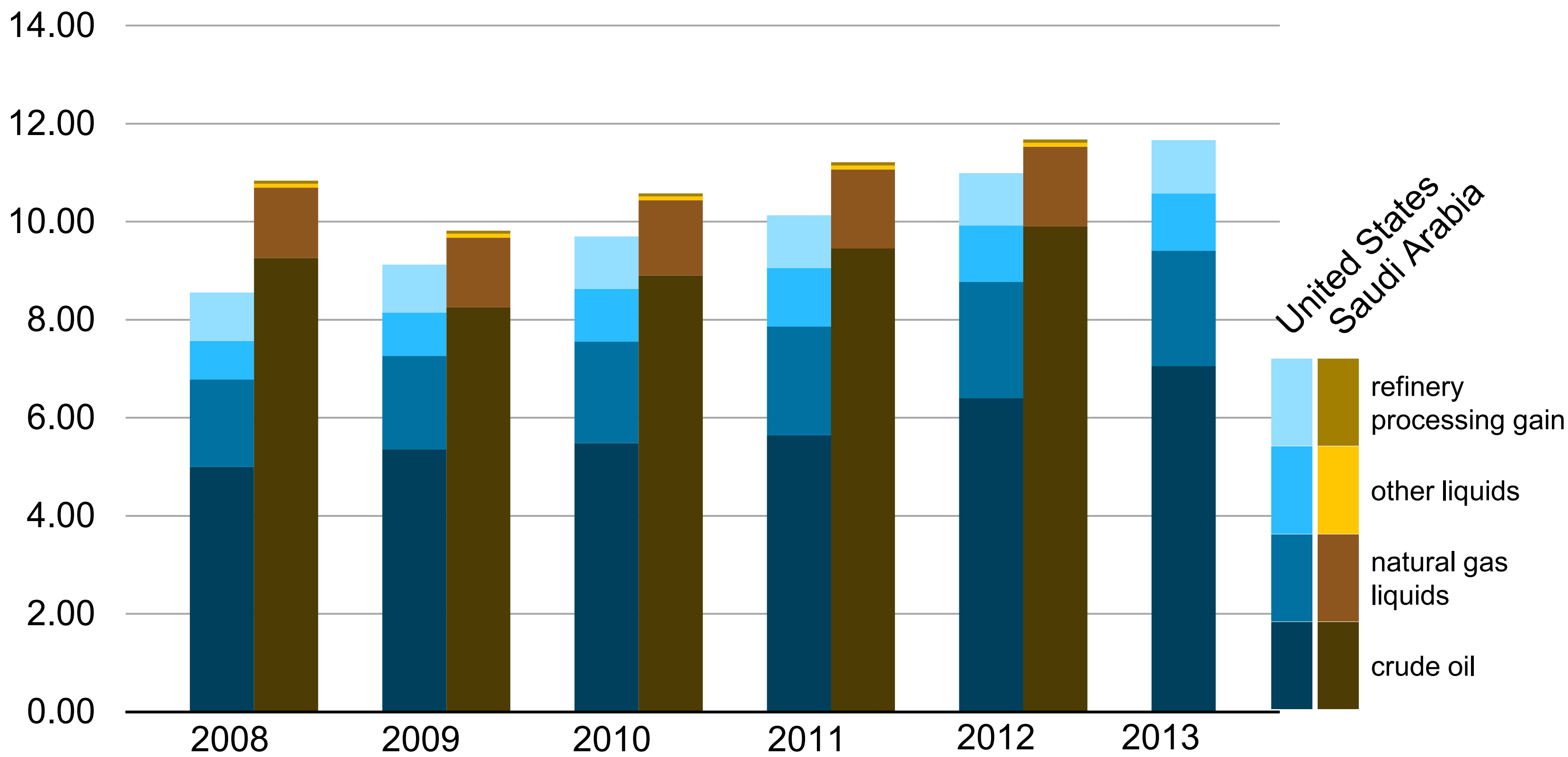


US production of tight oil has grown dramatically over the past few years (tight oil still requires more processing than conventional oil for gasoline production)



US and Saudi Arabian crude oil and petroleum liquids production (million barrels per day)

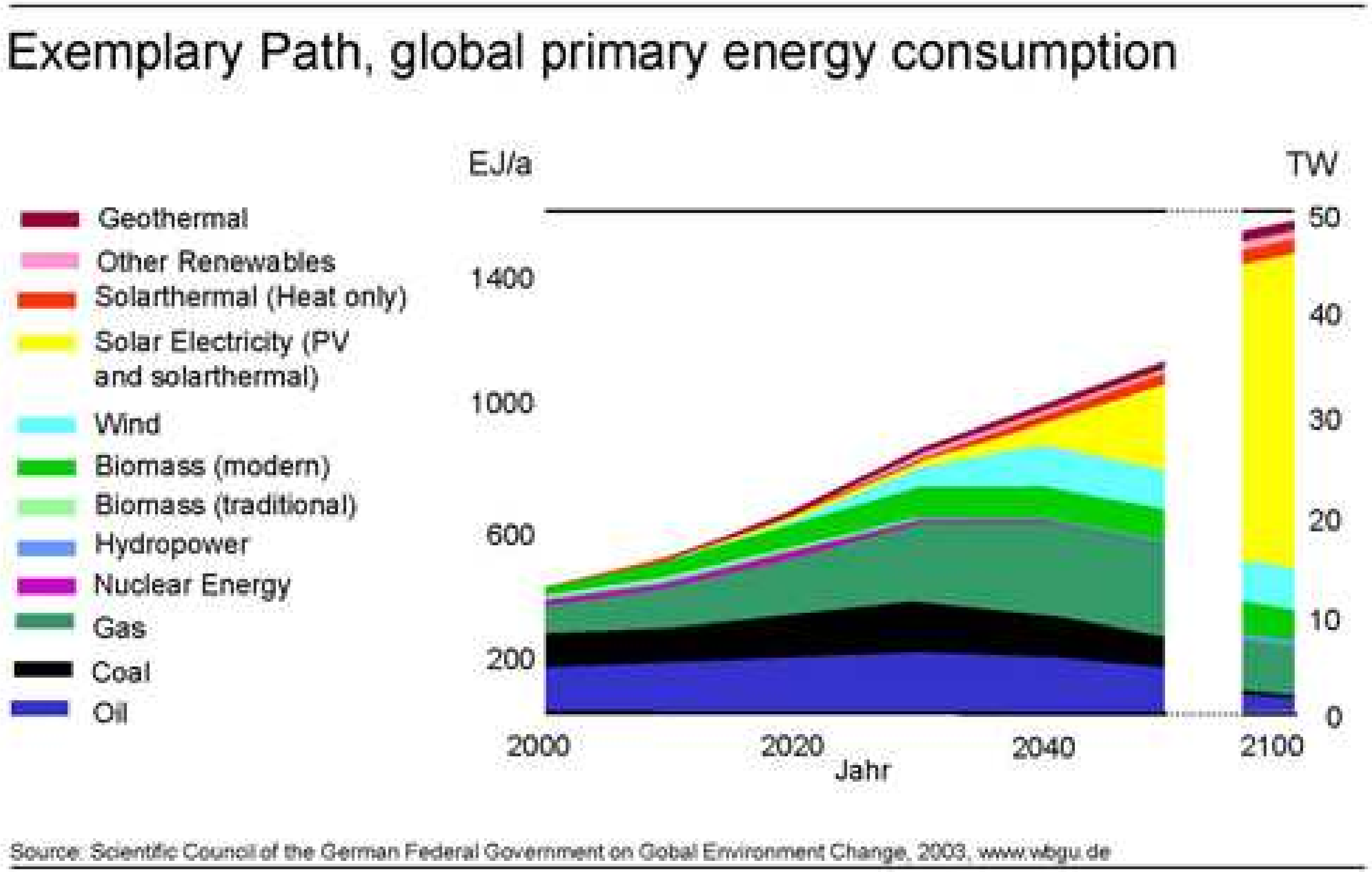
Now US is being changed from an oil-importing country to an oil-exporting country - becomes two majors.



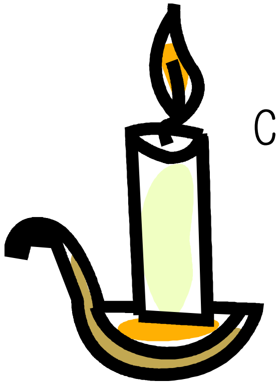
Conclusion of New Energy Sources

Currently, solar energy provide less that 0.5% of the U.S. power needs, but even with existing technology, it could provide up to 15% (major technology in clean energy resources).

Shale gas / oil will open new opportunities in conventional energy area.

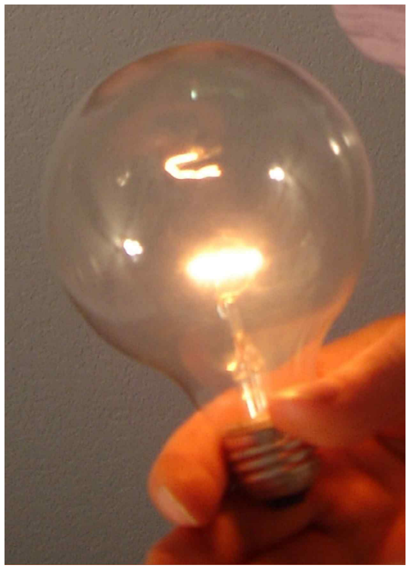


Each subsequent improvement in lighting led to major improvements in the energy efficiency of the light



Candle: 0.05 lumens per watt

Gas lamp: 0.5 lumens per watt



"Incandescent" Lightbulb
15 lumens per watt
(5% efficient)

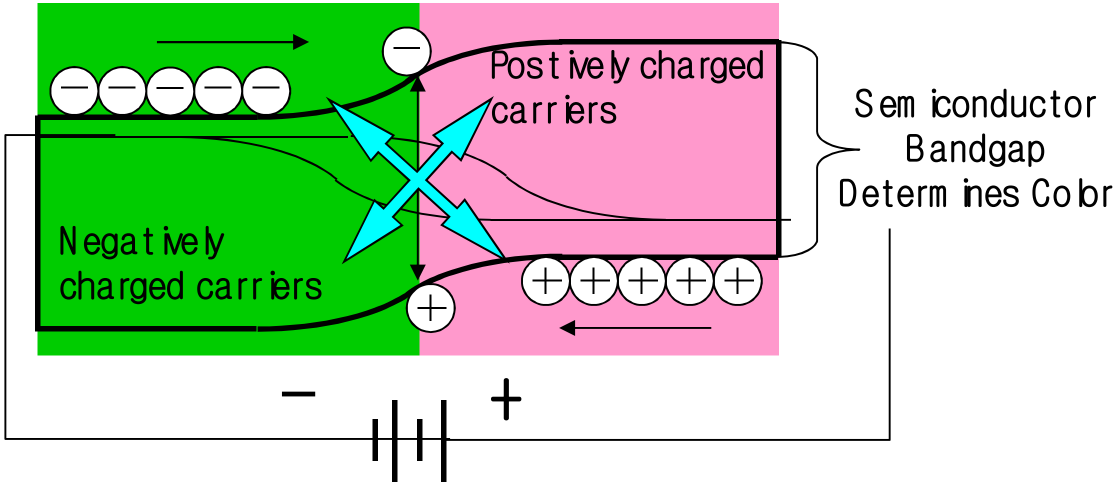
This bulb is no longer available in Korea (law)

Why does lighting impact energy conservation?

- Lighting consumes 22% of the electricity generated in the U.S.A.
- That's 8% of the total energy consumption
- Costs $50 billion per year
- Releases 150 million tons of CO_2 into the atmosphere each year
- Much of it is 19th century technology with poor efficiency

Light Emitting Diodes

Inorganic solid state lighting – Composition determines color



Colored LEDs:

Red – GaAs

Blue, Green - InGaN

White LEDs:

Red + Green + Blue, or Blue + phosphor

– With applied voltage positive and negative charge carriers recombine

– Energy may be released as light or heat

– Theoretically they can be 100% efficient with unlimited life!

(compared to incandescent which is 5% efficient, 2000 hour life)

– Commercial LEDs can be expected to reach 50% efficiency and possibly more

Buckingham Palace, London, England
Lit by Lumileds LEDs

Energy Storage Devices

Energy storage provides energy at a different time than when it was generated. For example, renewable energy is often intermittent (like wind and sun), and storage allows use at a convenient time.

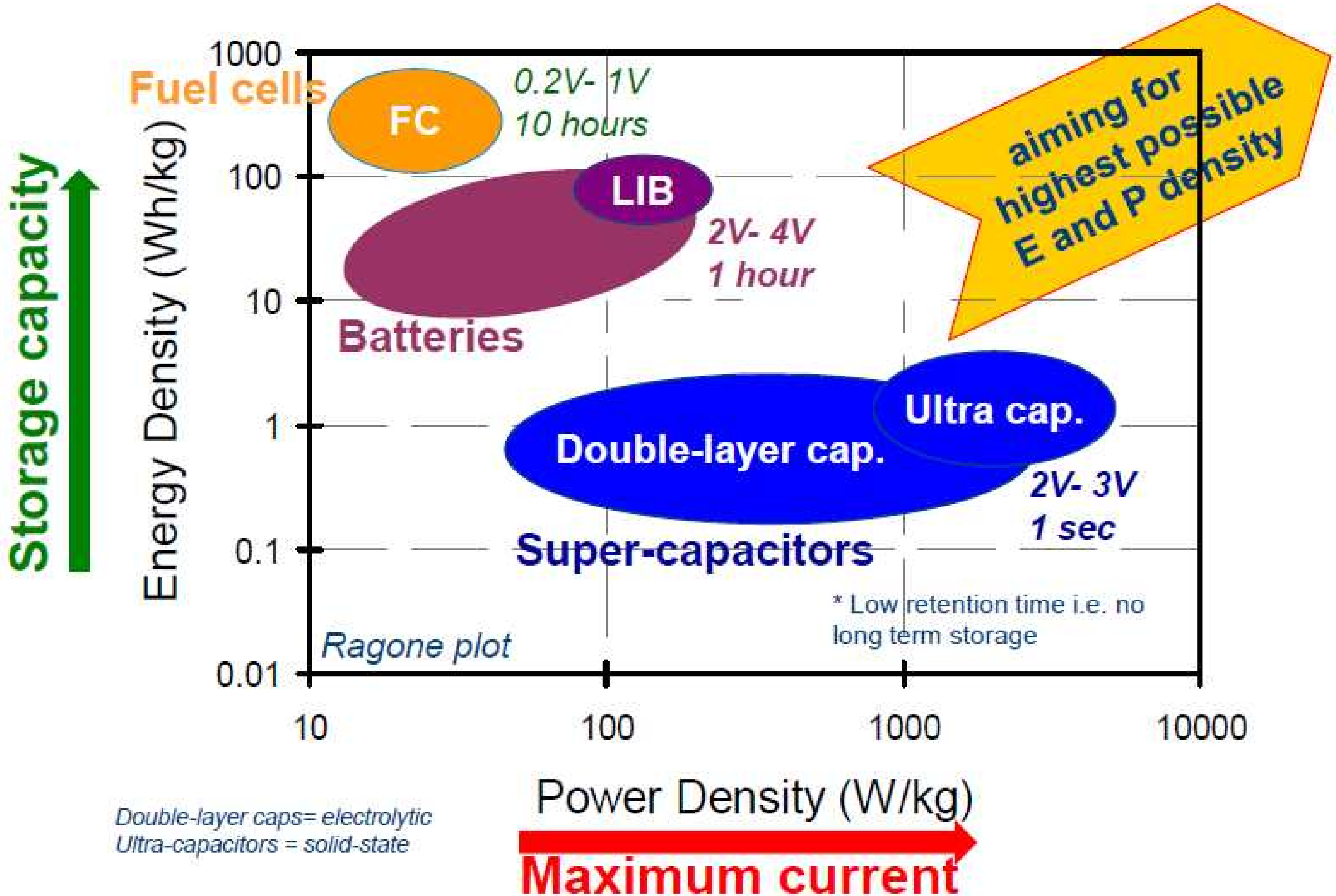
Conventional storage systems such as batteries continue to dominate. Short-term storage or energy-smoothing devices like ultracapacitors work well in the 10-second time range.

Diverse needs for storage of electricity

• **Primary power source:** personal electronics, automotive, microsystems and autonomous devices, implants, ...

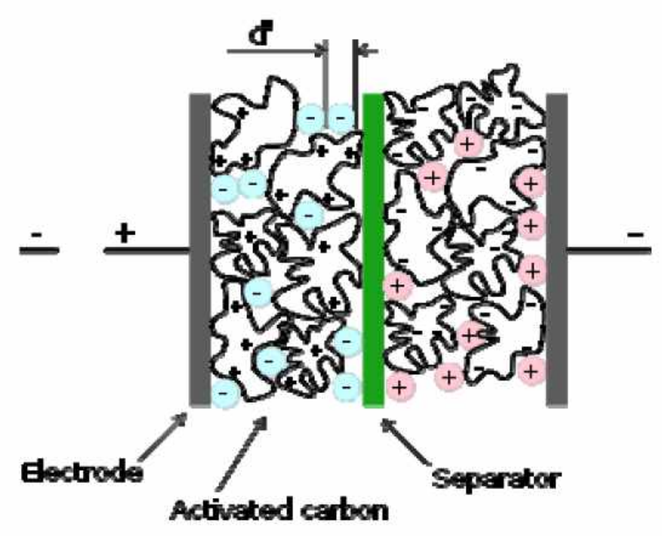
• **Temporary storage:** temporary storage of excess electricity for smart power grid (intermittent power production), emergency back-up primary power source (hospitals, terminals,...)

• **Buffering:** for improved efficiency and distribution (smart solar modules, electrical vehicles, …)

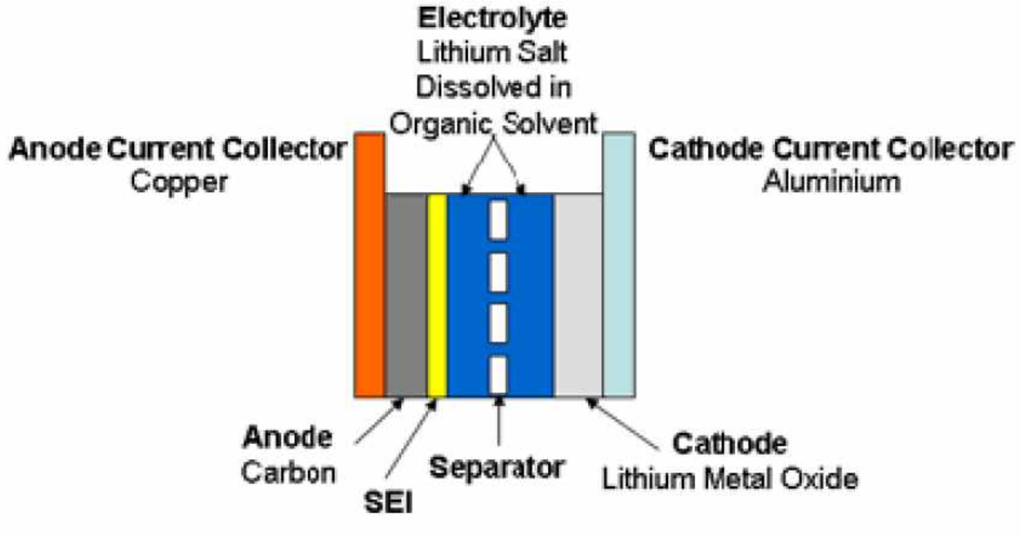


Double-layer caps= electrolytic
Ultra-capacitors = solid-state

Supercapacitors



Batteries



Storage capacity is determined by surface area
charge is electrostatically stored **on surface**
Best suited to storage periods of 0.1second to 10 seconds

Storage capacity is determined by volume (mass) of cathode/anode
charge is electrochemically stored **inside the material**
Best suited to storage periods of 1second to 60 days

Energy Storage Devices

- Largest battery energy storage station in Zhangbei, China

$LiFePO_4$ batteries (BYD) for 36 MWh

Conclusion

Conventional Technology (Oil and Nuclear)

Transportation – Internal Combustion Engine (Gasoline / Oil)

Heating – LNG (methane) or LPG (propane or butane) / Oil

Electrical Power Generation – Coal, Gas (Oil), Nuclear, Others

Novel Technology (Shale, Solar, LED and SC/Battery)

New Oil and Gas Technology – Shale Gas / Tight (Shale) Oil

New Transportation Technology – Electricity Based Engine (Motor)

Novel Electricity Generation – Wind, Hydro, Geothermal, Biomass, Solar (increasing)

Electricity Storage (Power Supply Smoothing) – Battery, Supercapacitor

Energy Efficient Devices – LED, Low power consumption electronics

Scope of the Course

Photovoltaic Devices (& PD)

Energy Efficient Devices (LED)

Storage (SC / BT) Devices