Week 1 Day 2

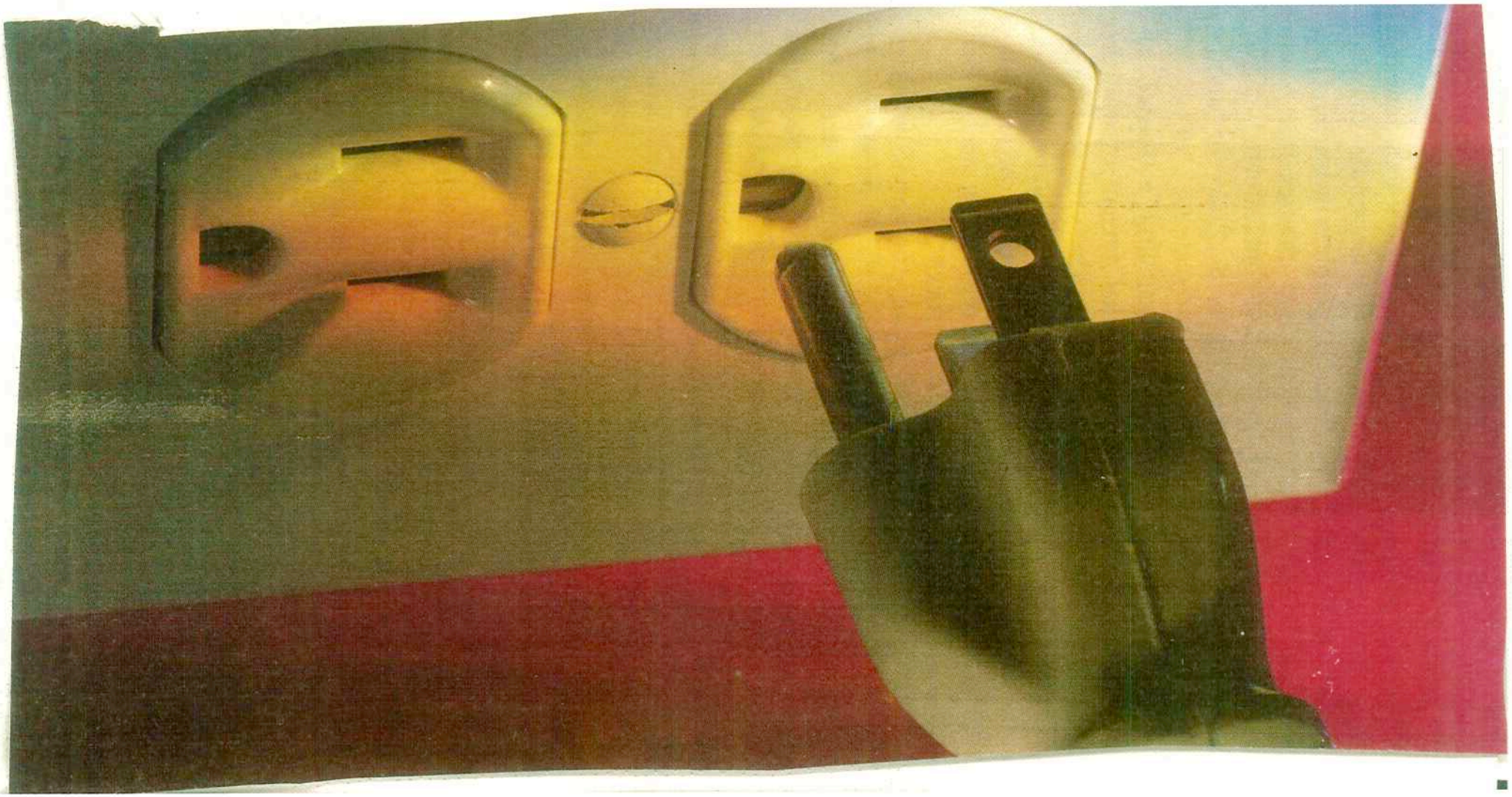
Introduction Continued

- Distribution Basics
  - Basics
  - Power Quality
  - Overview of Grid
- Distribution Components
- Fossil Fuel
  - Oil
  - Coal
- Nuclear

Connect to the grid

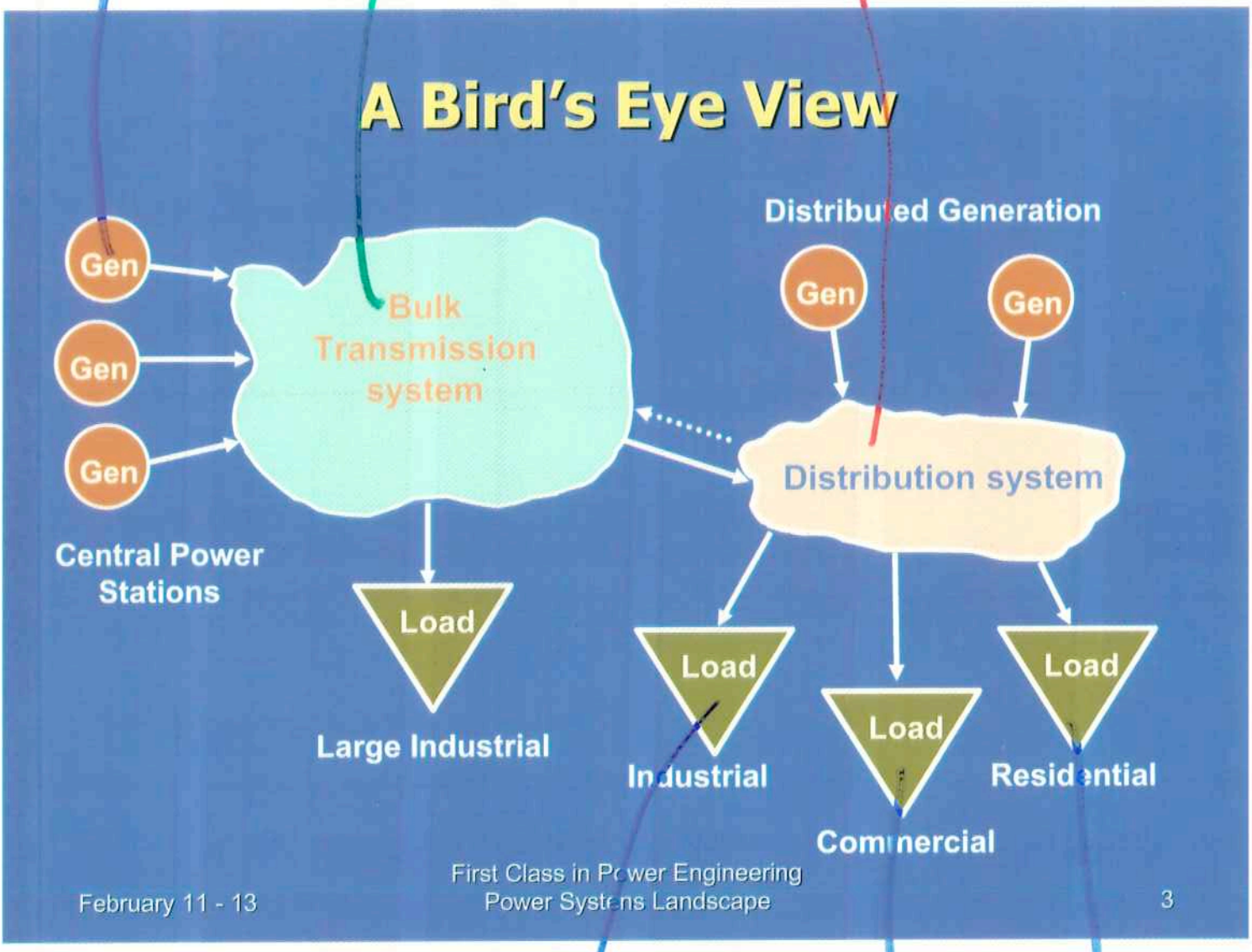
power network

MV @ 10^2 A can feed 10^4 loads each 10KW ⟶ @ 100V ⇒ 100 A service



A Bird's Eye View

- Generating stations – make power
- Loads – use power
- Bulk transmission system – move power to the distribution system
- Distribution system – move power to the loads



20kV

10^6 V

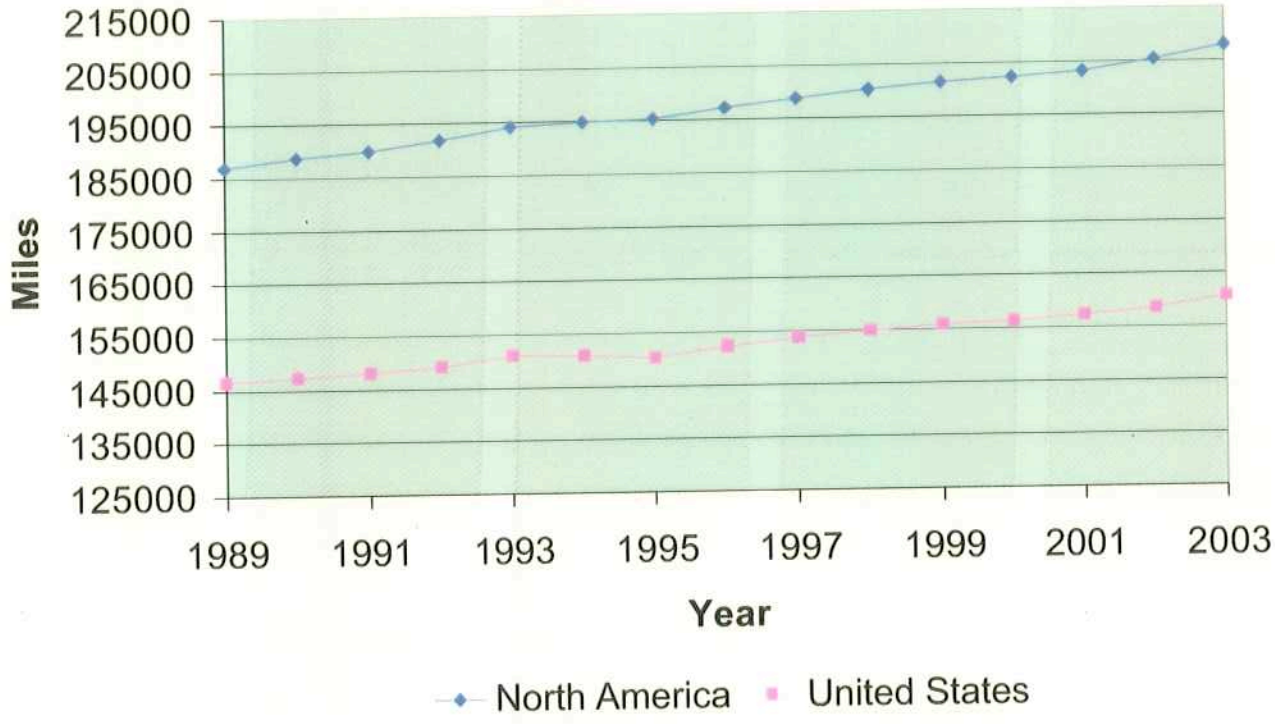
10^4 V

480 V

220

110

Miles of Transmission Line 230 kV and Above



Bulk Transmission System

Facility Site Selection: Political Criteria

- **aesthetics**
- **public safety**
- **use of existing encumbrances**
- **use of public versus private land**
- **environmental**

North American Power Grid

Interconnected transmission

- **100 (varies) – 750 kV**
- **High Voltage DC**
- **3 A-synchronous areas**

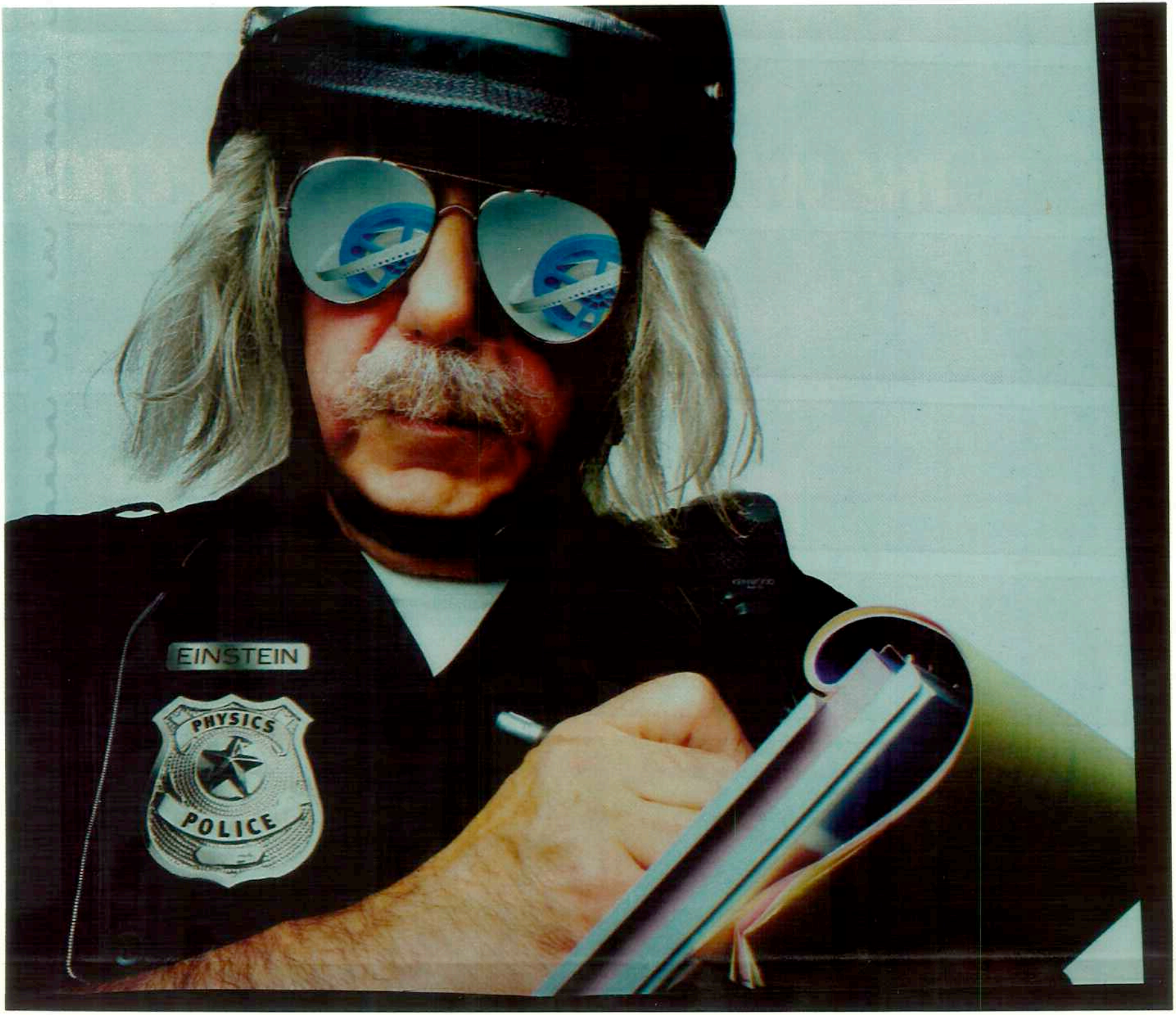
Radial distribution

- **2.4 – 34.5 kV**

Bulk Transmission System

Laws of Physics

- **electricity follows its own path**
  - **can not be legislated**
  - **does not honor control area boundaries**
  - **does not honor international borders**

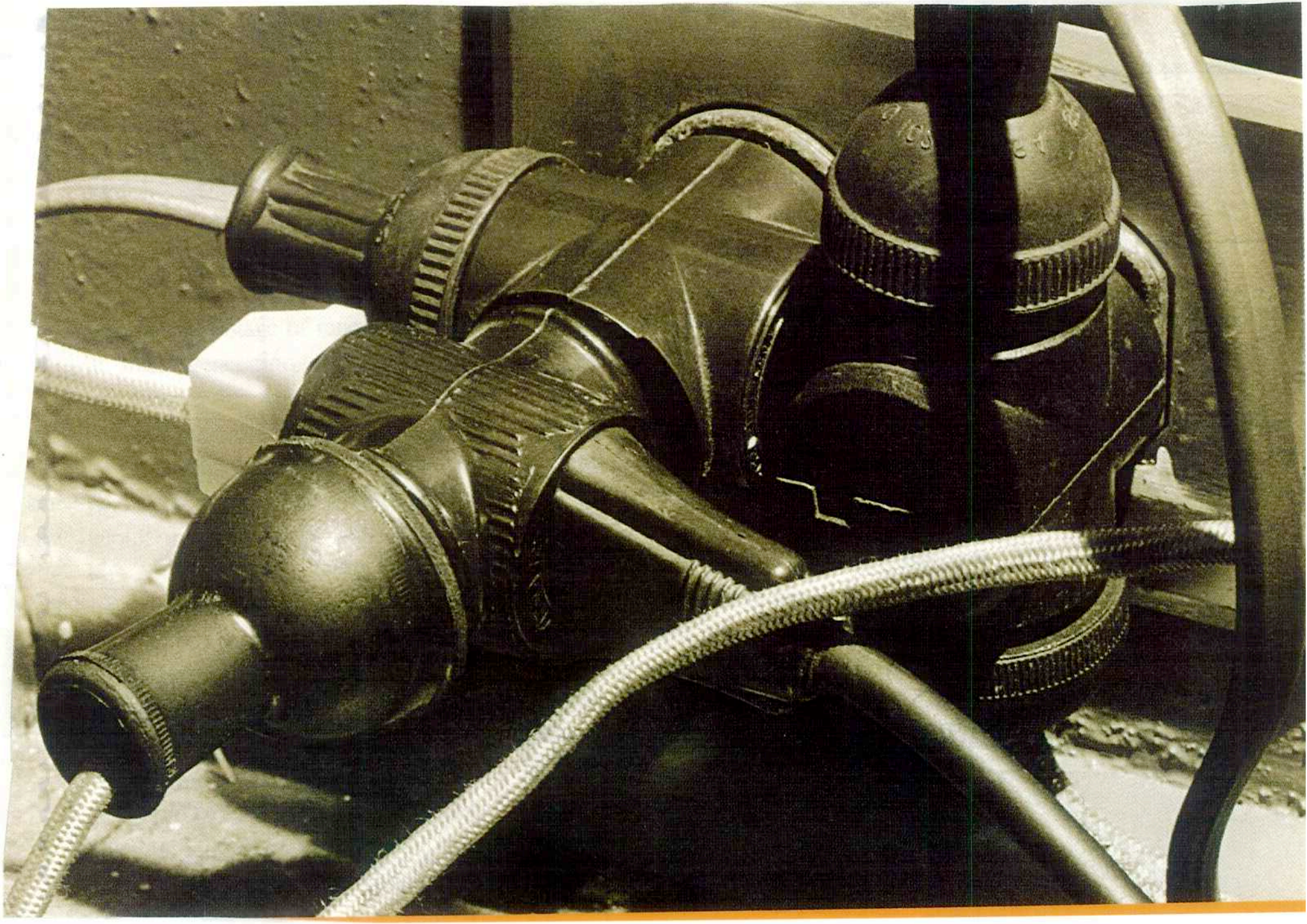

EINSTEIN
PHYSICS
POLICE

Generating stations

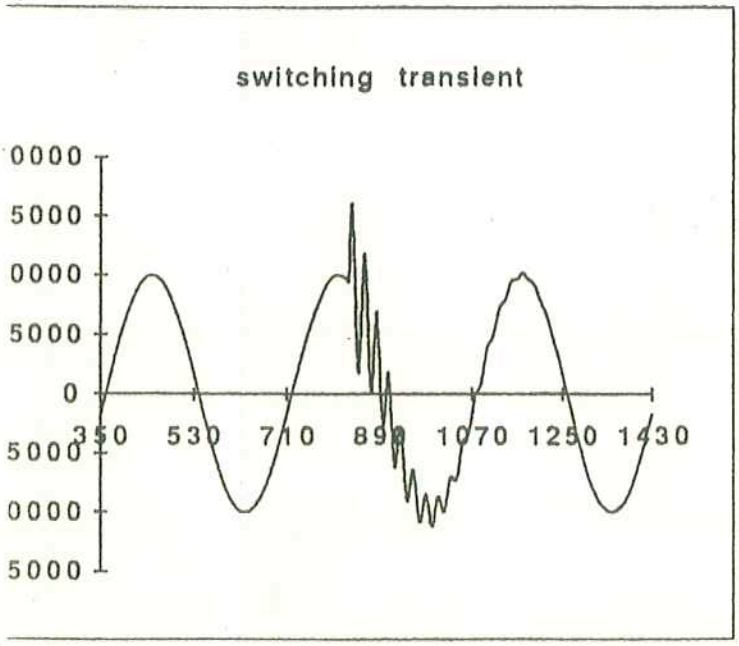
Technologies: Fossil Fueled

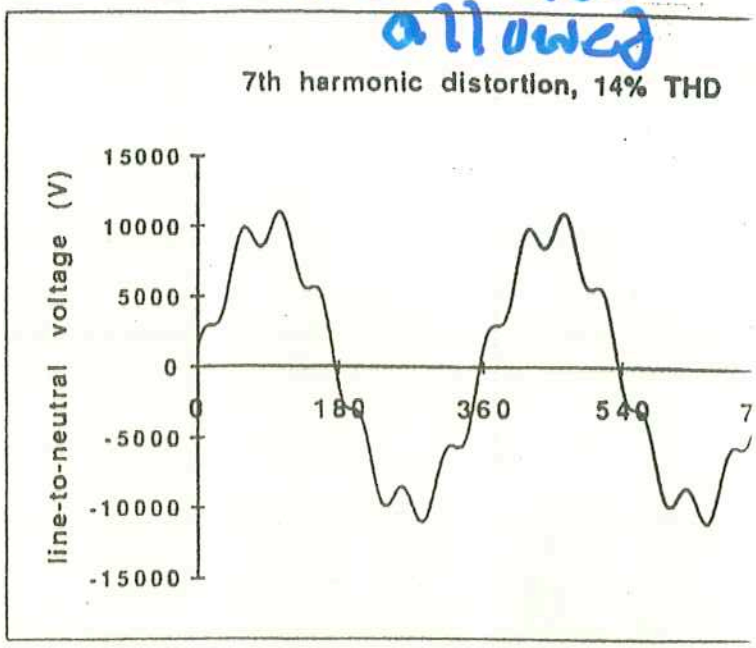
- **boiler/steam turbine**
  - **coal**
  - **oil**
  - **gas**
- **Combustion turbine**
  - **gas**
  - **oil**
  - **coal gasification**

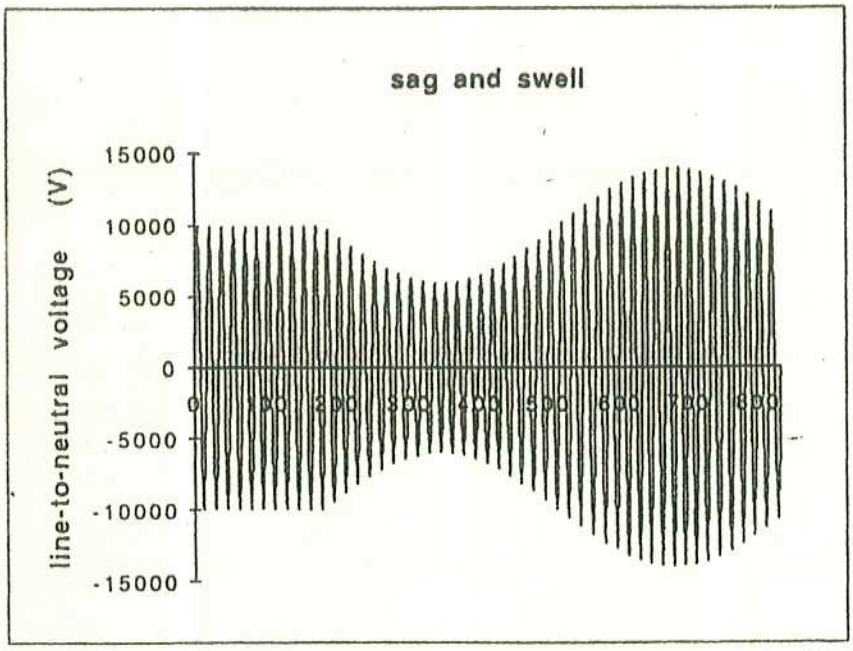
578 MW Steam Turbine/Generator

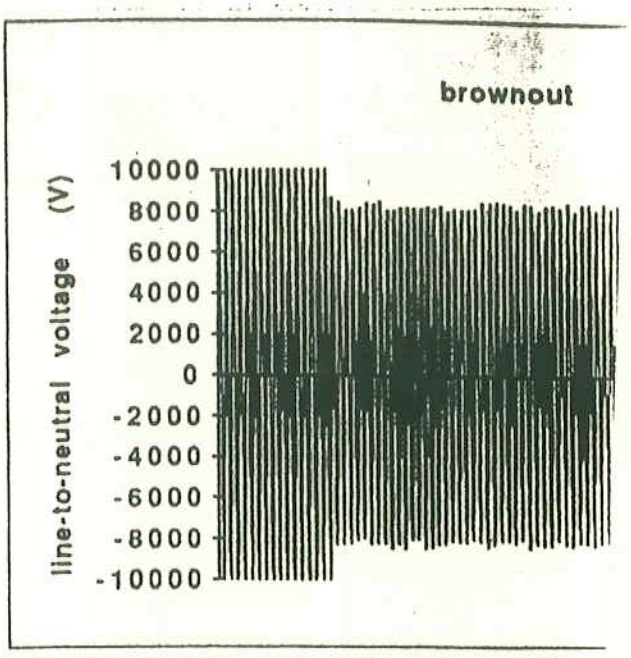


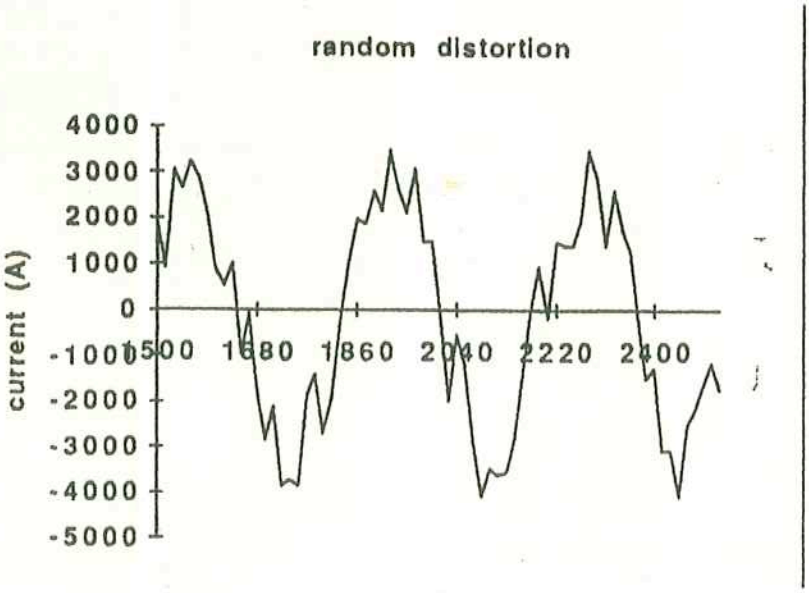
Real AC input line: 85 - 160 V allowed

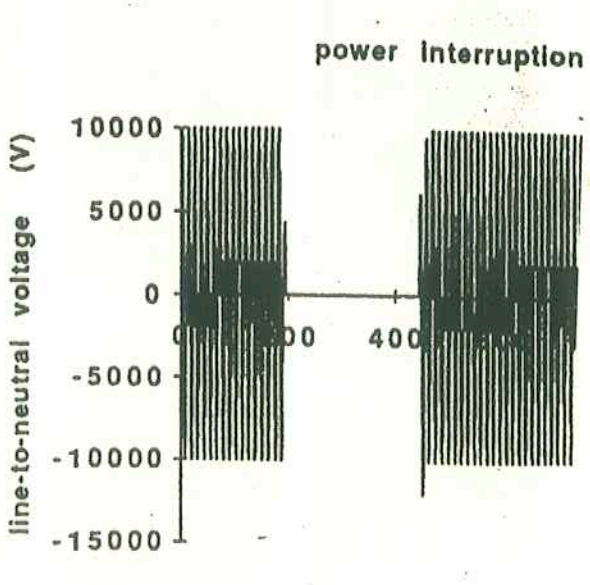












VIPer Range

Part Number	Package	European Voltage Range (195-265 Vac)	US/Wide Voltage Range (85-265 Vac)
VIPer53DIP VIPer53SP	DIP-8 PowerSO-10	50W 65W	30W 30W
VIPer22ADIP VIPer22AS	DIP-8 SO-8	20W 12W	12W 7W
VIPer12ADIP VIPer12AS	DIP-8 SO-8	13W 8W	8W 5W

$V_{out}(t)$ for a battery?
Paper #1 with chip

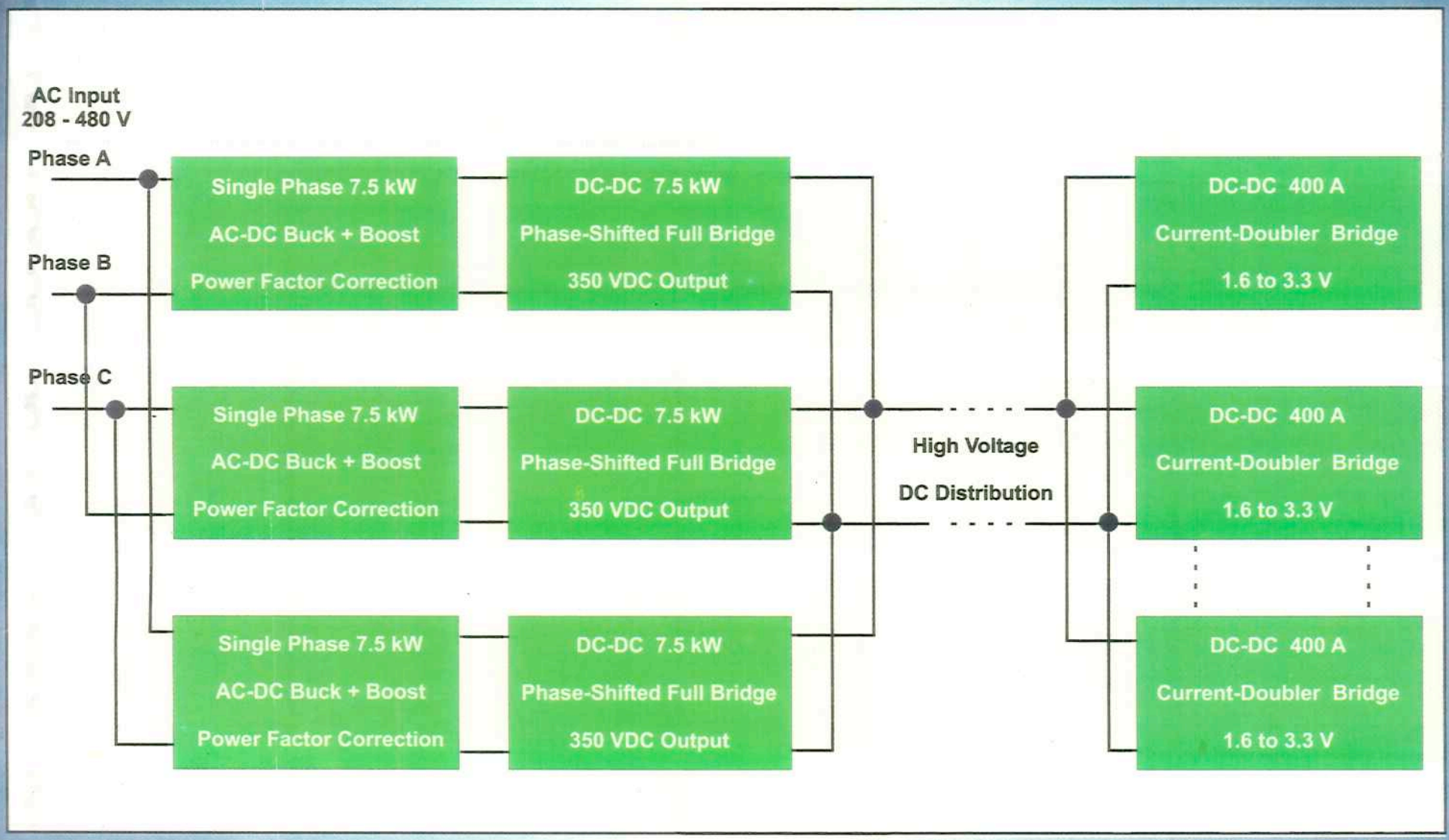


Fig. 1: Present Architecture of IBM Server Power System

Bulk Transmission System

System Design: Maintenance/Safety

- **Must be maintainable**
  - **redundancy**
  - **isolation**
- **Must be safe to operate**
  - **clearances**
  - **visible isolation**
  - **installed infrastructure**

Bulk Transmission System

Laws of Physics

- **no storage**
  - **produced at the instant it is used**
  - **generation must exactly match load**

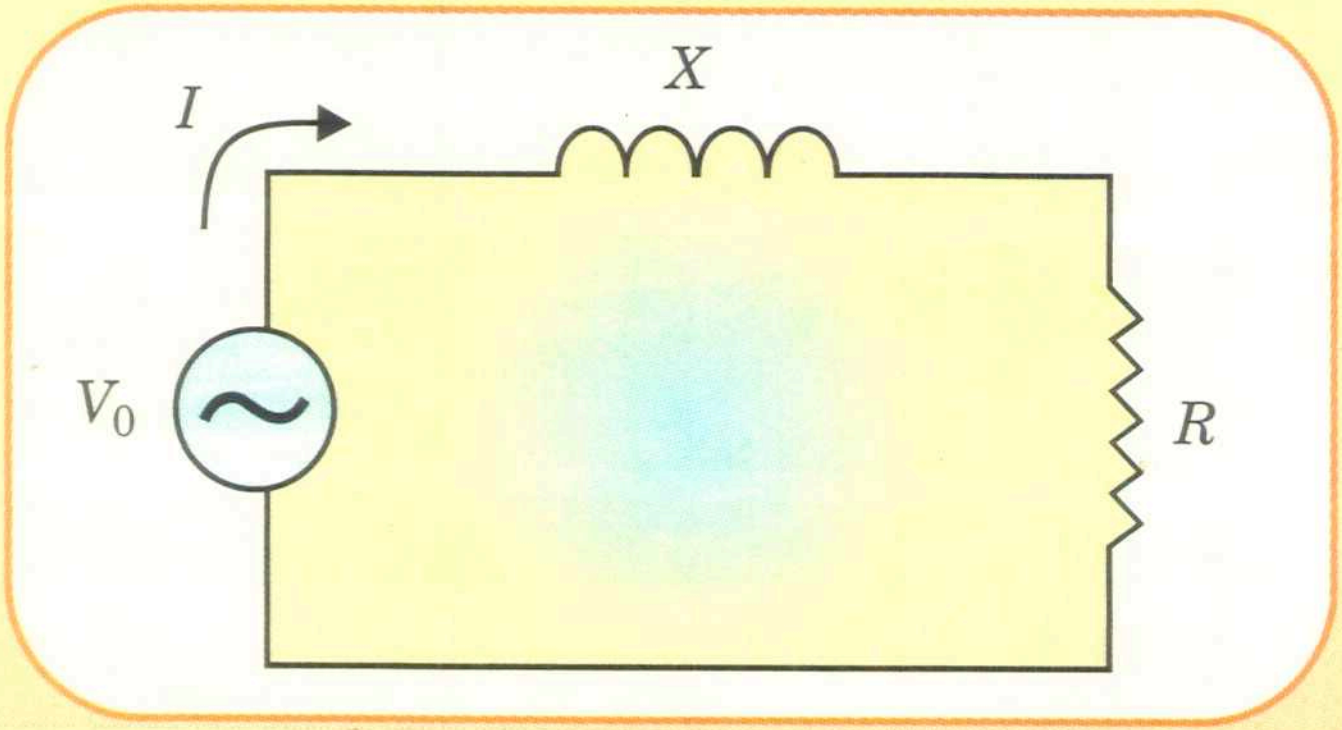


Figure 5. A model circuit. An AC voltage source V_0 generating a current I through a resistance R and inductor X models important features of transmission in the electric power grid.

No room for weak links.

North American Power Grid

Interconnected transmission

- **100 (varies) – 750 kV**
- **High Voltage DC**
- **3 A-synchronous areas**

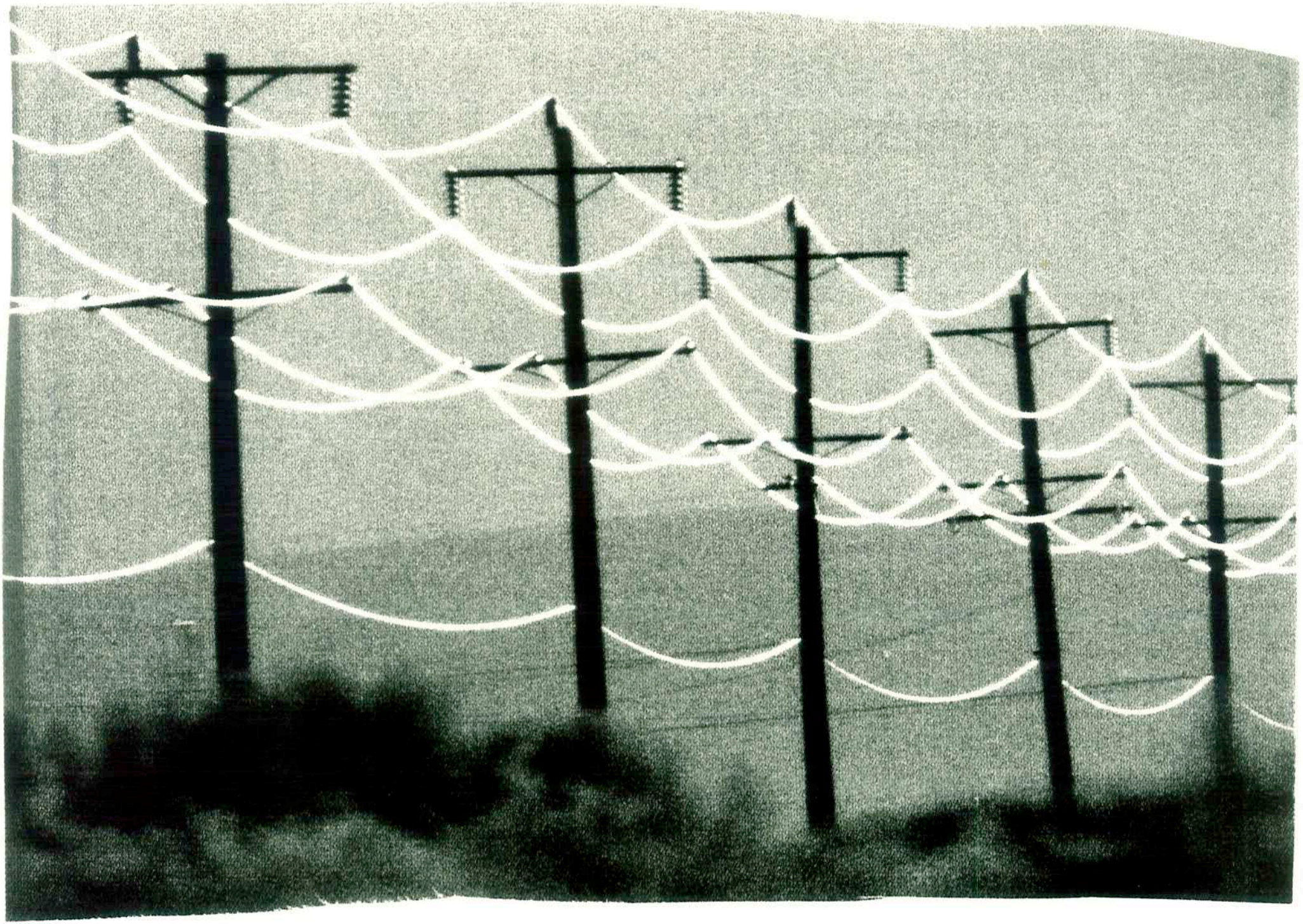
Radial distribution

- **2.4 – 34.5 kV**

Bulk Transmission System

Hardware: Transmission Lines

- **AC versus DC**
- **structures**
  - **single/double/triple circuit**
  - **wood**
  - **steel lattes**
  - **steel self-support**
  - **steel direct embedment**



Bulk Transmission System

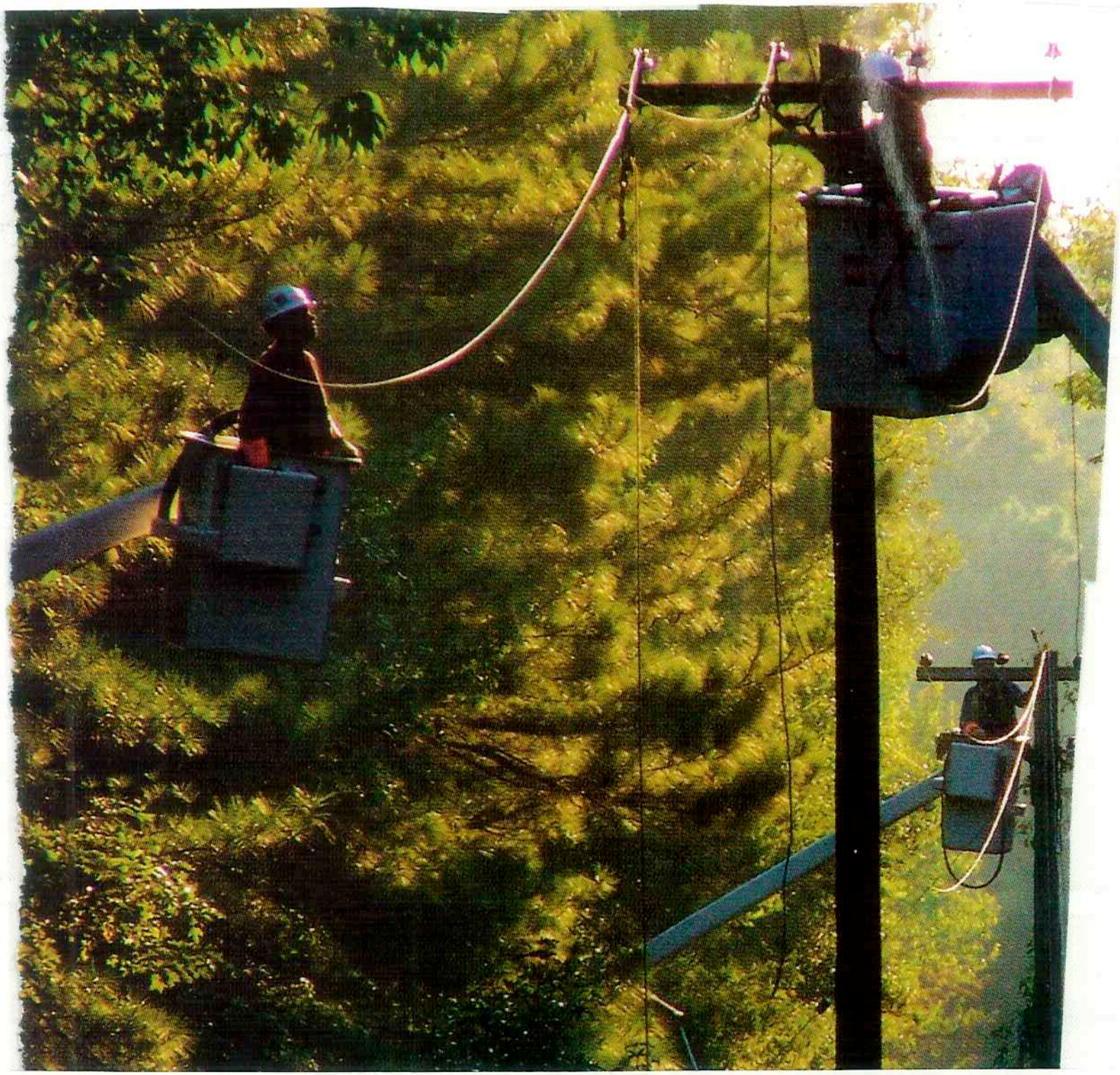
Hardware: Transmission Lines

- **Switches (disconnects)**
  - **group operated air break (GOAB)**
  - **hook stick operated**
  - **load break**
  - **interrupters**
  - **motor operated (MOD)**

Bulk Transmission System

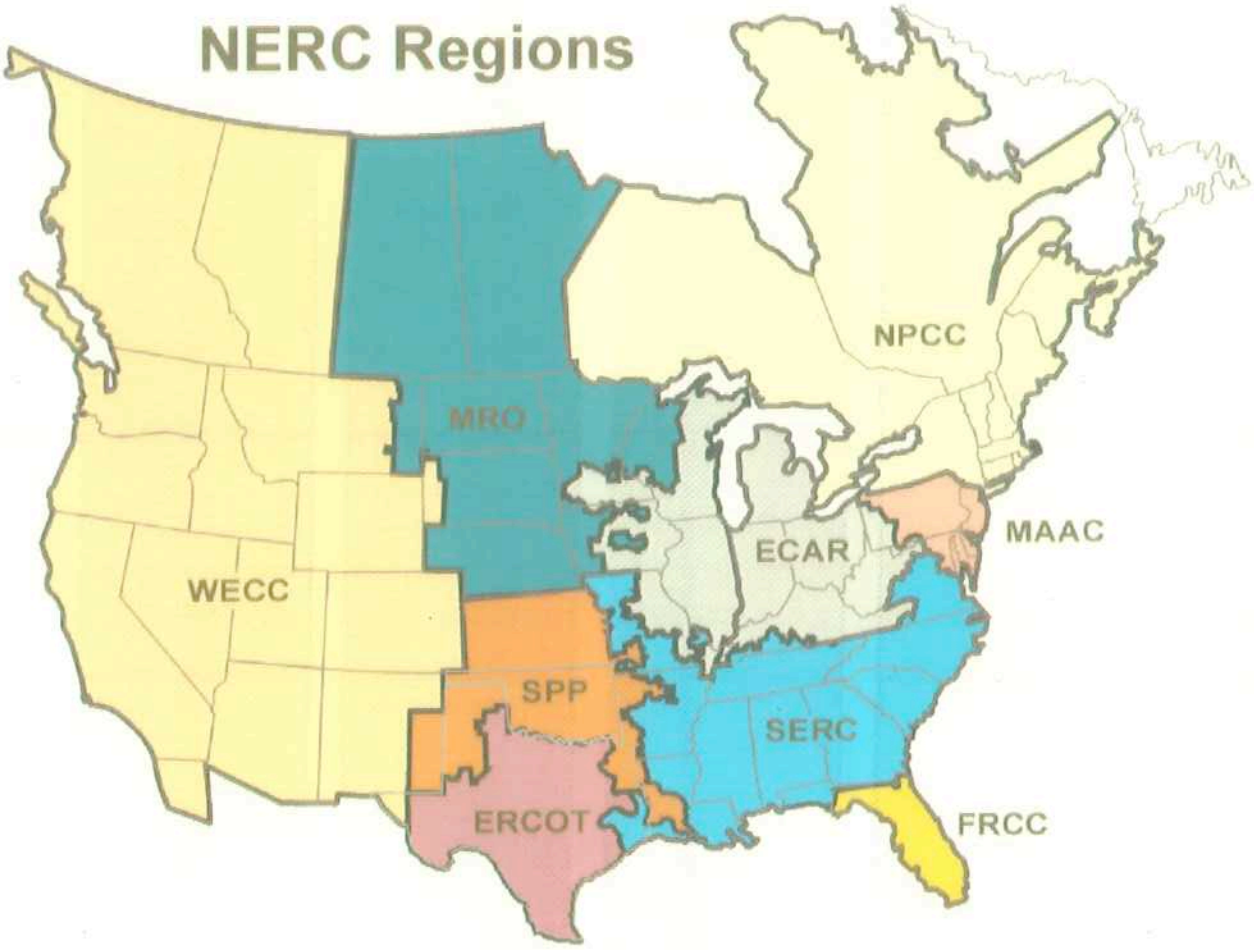
Hardware: Transmission Lines

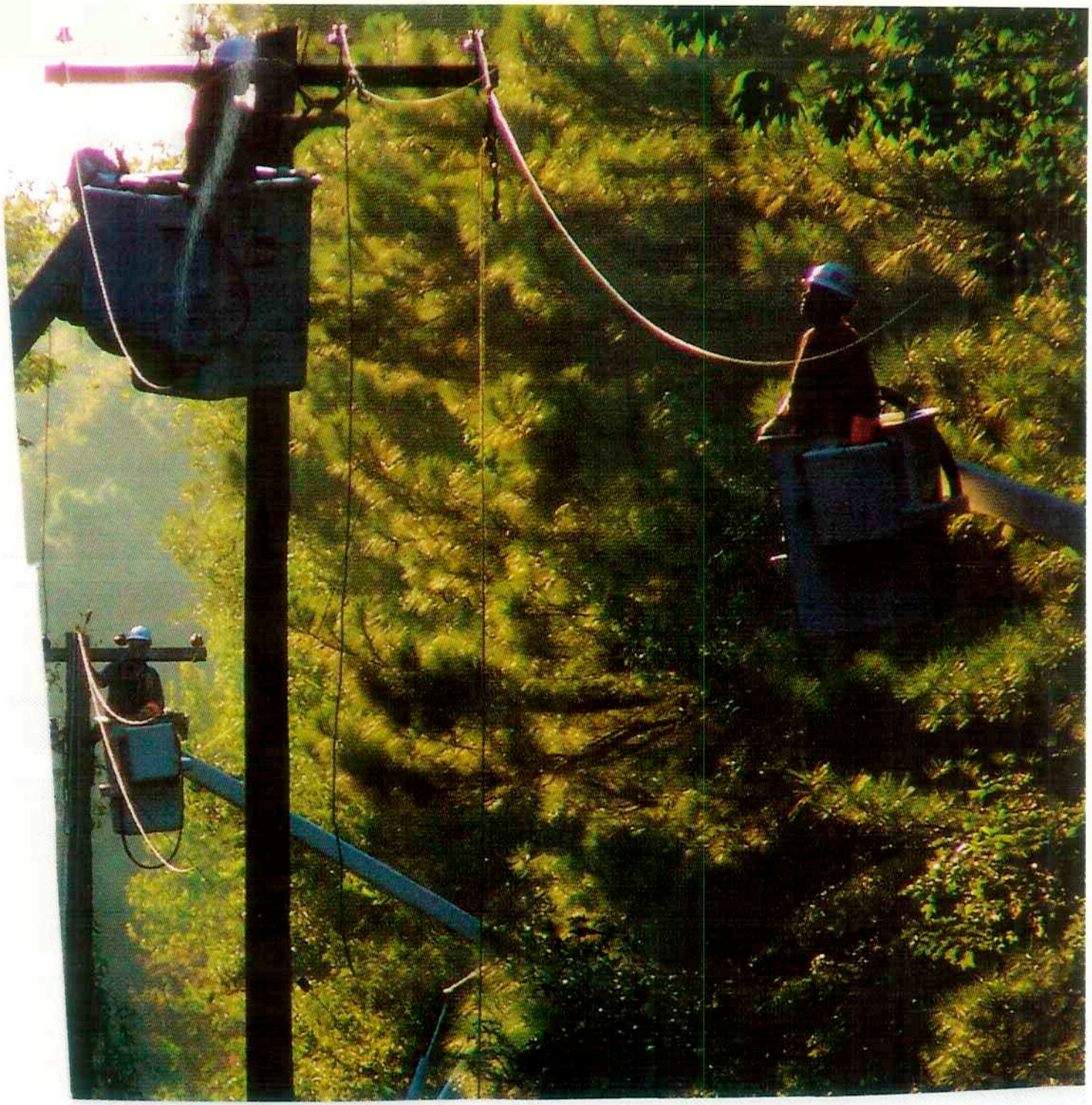
- **insulators**
  - **glass**
  - **polymer**
- **compensation**
  - **series capacitors**
  - **shunt reactors**



Electric Utility Industry Organization

- Federal Energy Regulatory Commission (FERC)
- Public Utility Commissions (PUC)
- North American Electric Reliability Council (NERC)


NERC Regions
NPCC
MRO
MAAC
ECAR
WECC
SPP
SERC
ERCOT
FRCC



Electric Utility Companies

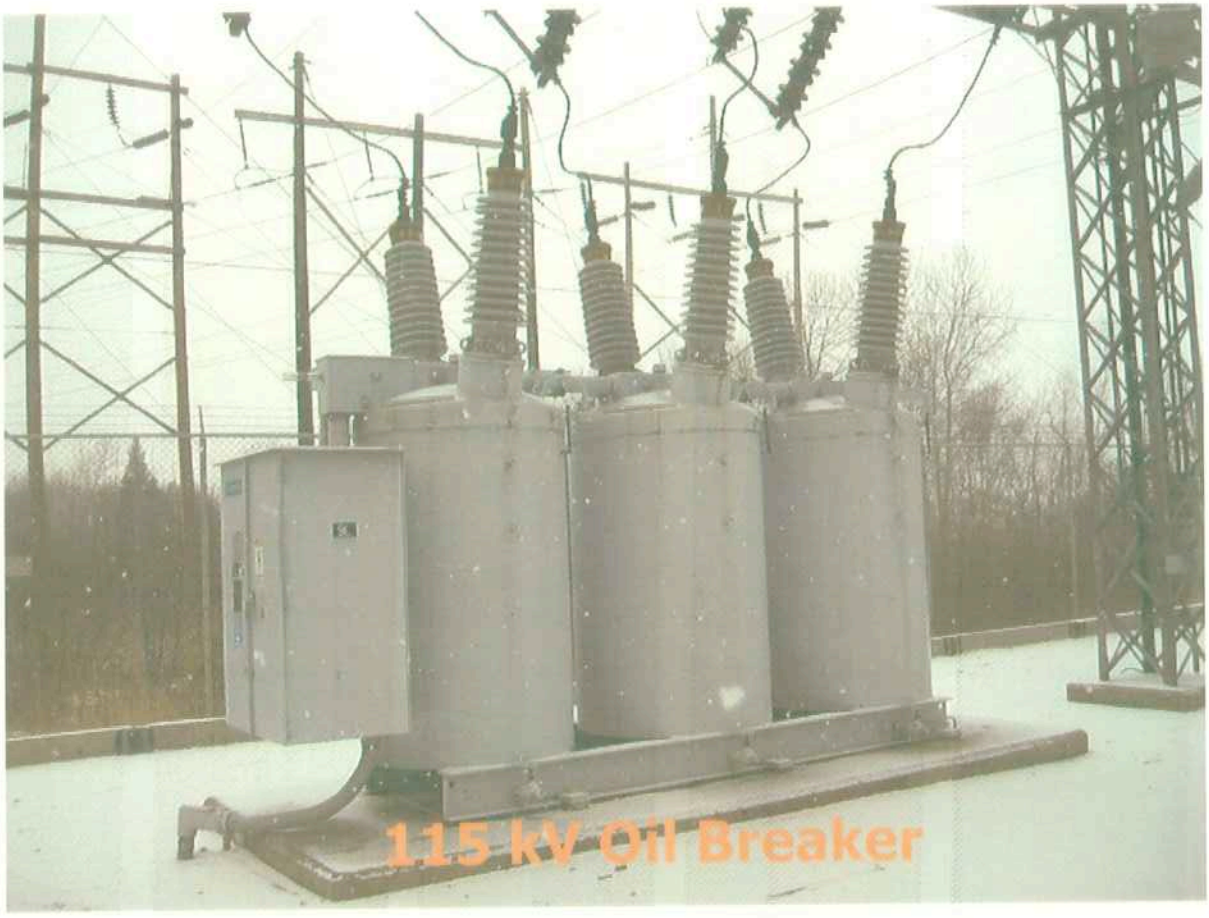
- Public Power (municipals, PP districts, etc)
- Cooperatives
- Investor Owned
- Private

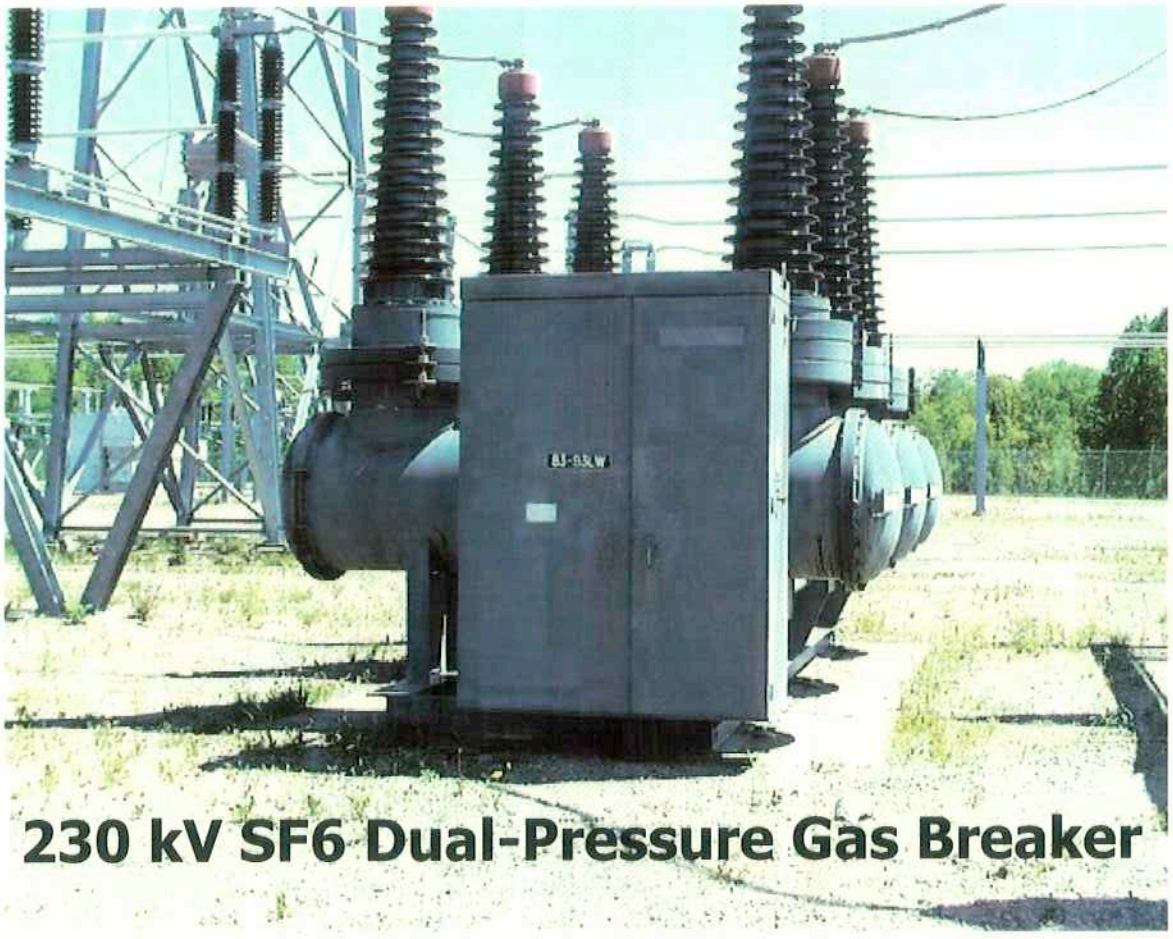
Bulk Transmission System

Hardware: Substations

- **Breakers**
  - **live versus dead tank**
  - **oil (OCB)**
  - **vacuum (VCB)**
  - **SF6 dual pressure**
  - **SF6 puffer**
- **circuit switchers**

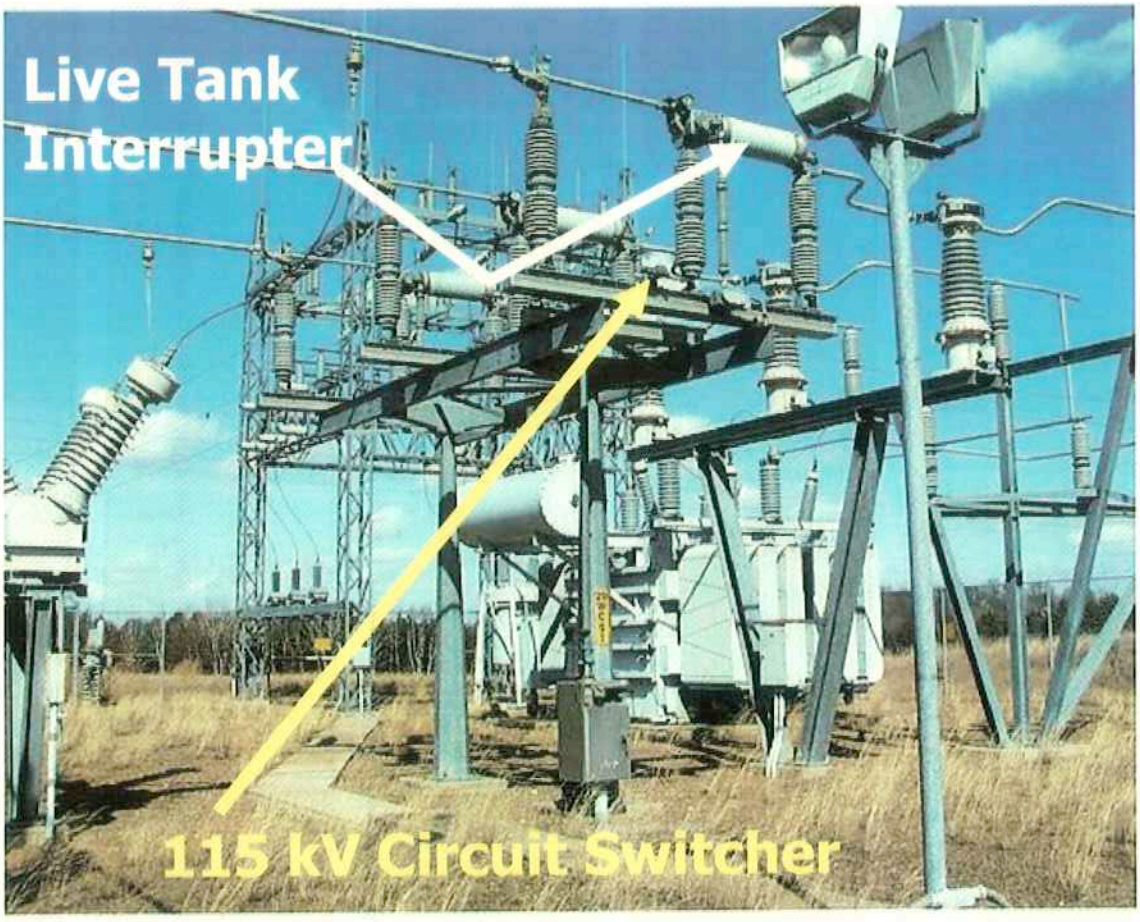
500 kV Live Tank Gas Breaker


115 kV Oil Breaker



230 kV SF6 Dual-Pressure Gas Breaker


230 kV SF6 Puffer Gas Breaker

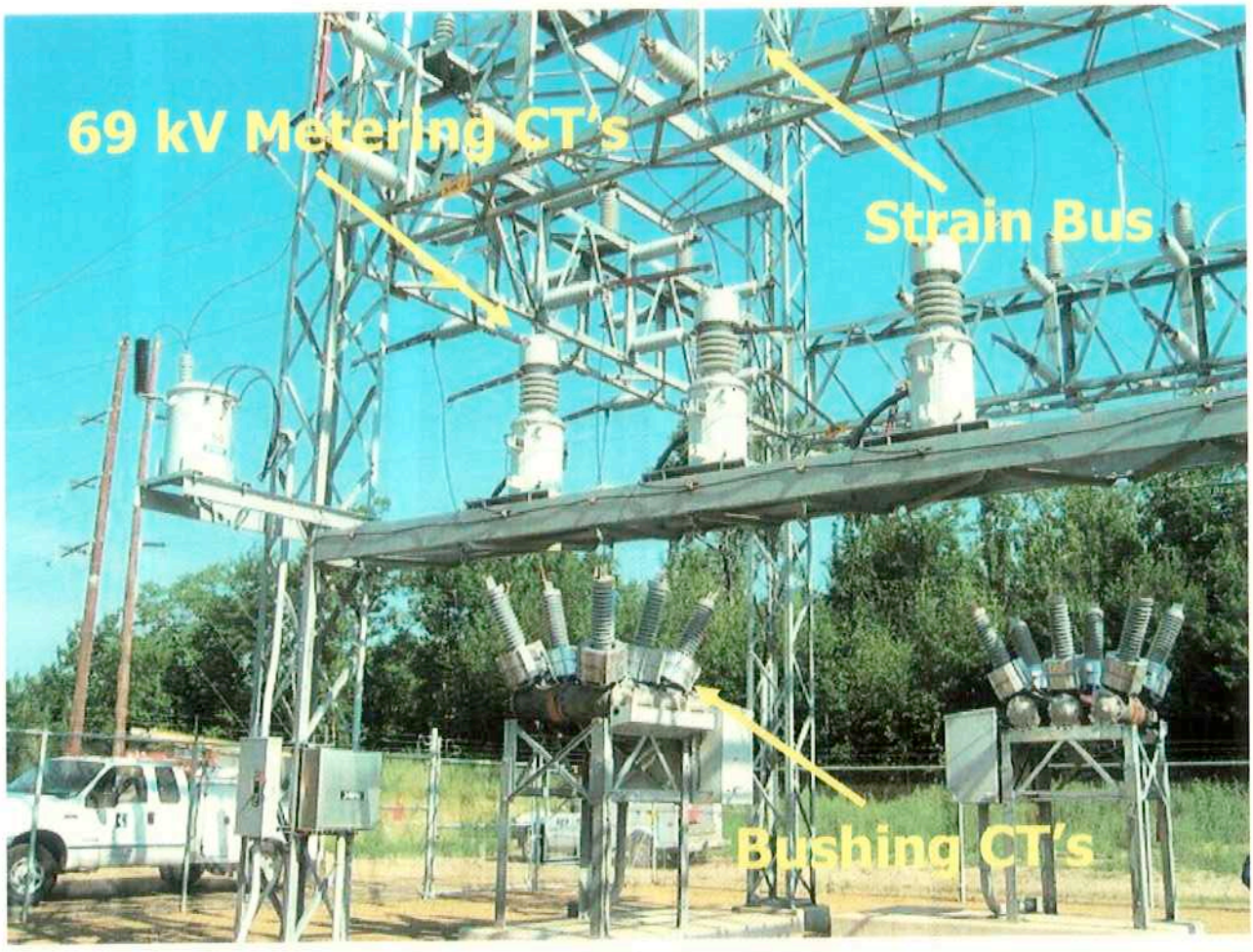

Live Tank
Interrupter
115 kV Circuit Switcher

Bulk Transmission System

Hardware: Substations

- **surge (lightning) arrestors**
- **relaying and control**
- **metering**
- **system control and data acquisition (SCADA) (supervisory)**


115 kV VT


69 kV Metering CT's
Strain Bus
Bushing CT's

Bulk Transmission System

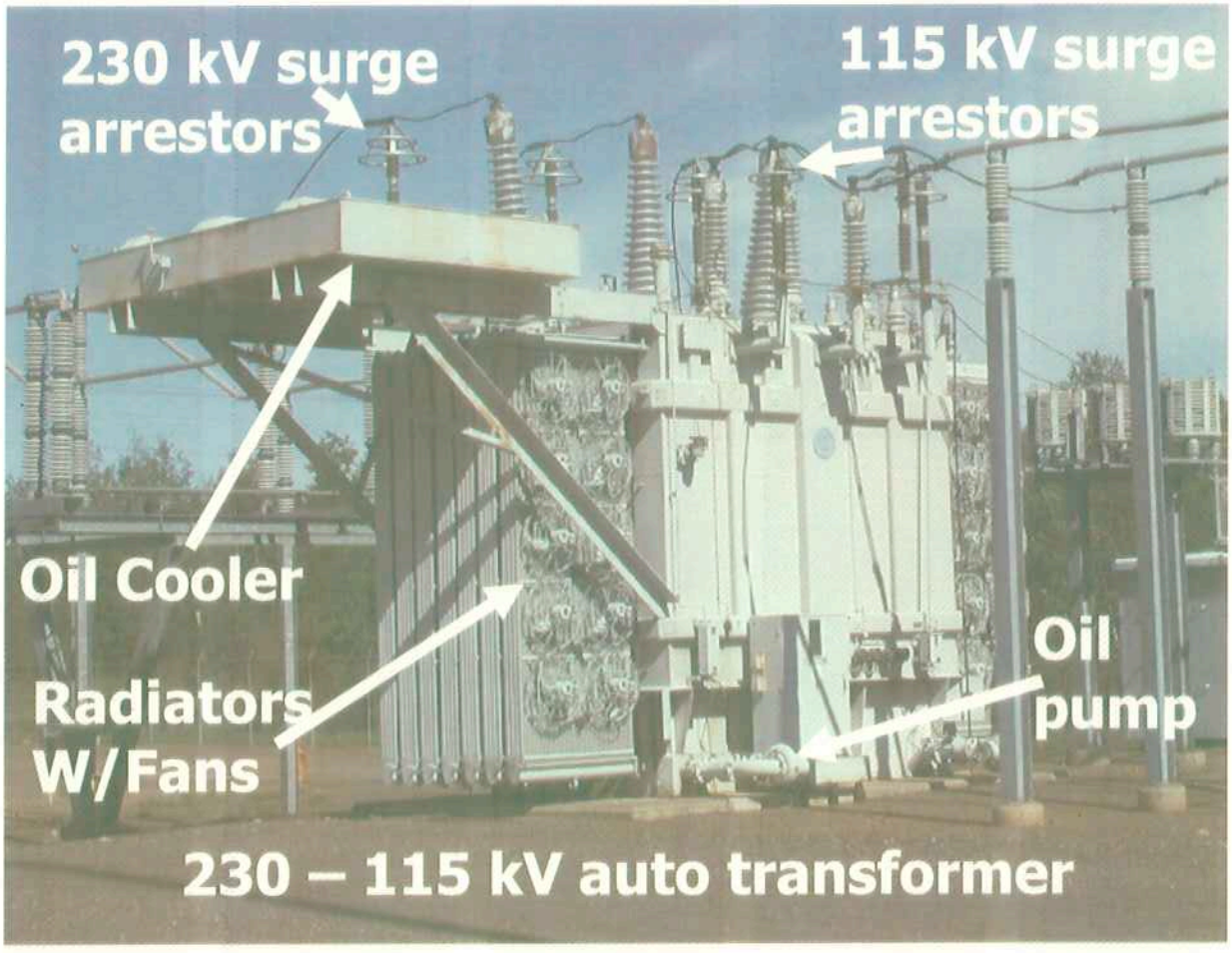
- **Hardware: Substations**
  - **power transformers**
    - **insulating medium (oil, air, cast)**
    - **MVA ratings/cooling systems**
    - **2/3/auto windings**
    - **tap changers**
      - **no-load**
      - **load (LTC)**
    - **phase shifts**

Bulk Transmission System

Hardware: Substations

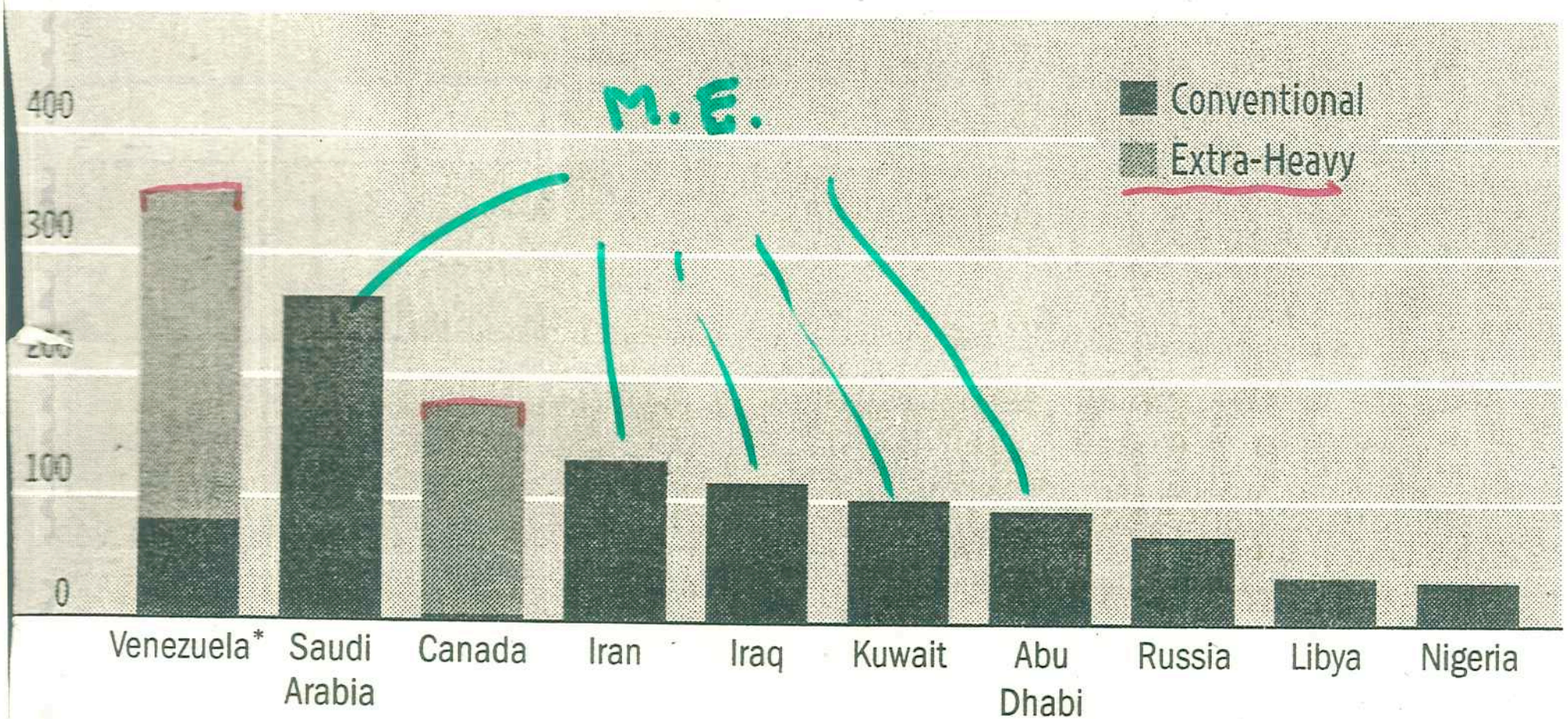
- **bus-work**
  - **Rigid (tubular, angle, etc)**
  - **Strain (cable)**
- **instrument transformers**
  - **current transformers (CT)**
  - **voltage transformers (VT or PT)**


230 kV rigid (tubular) bus


230 kV surge arrestors
115 kV surge arrestors
Oil Cooler
Radiators W/Fans
Oil pump
230 – 115 kV auto transformer

Heavy Lifting

Venezuela and Canada jump to the top of the oil patch when extra-heavy reserves are counted along with conventional sources. In billions of barrels:



*Amount of extra-heavy oil in Venezuela is a rough estimate only.

Sources: BP PLC; Oil & Gas Journal; Alberta Energy and Utilities Board; Canada's National Energy Board

Key Supplier

Top U.S. imports of crude oil and products by country of origin, January 2006

Source: Energy Information Administration

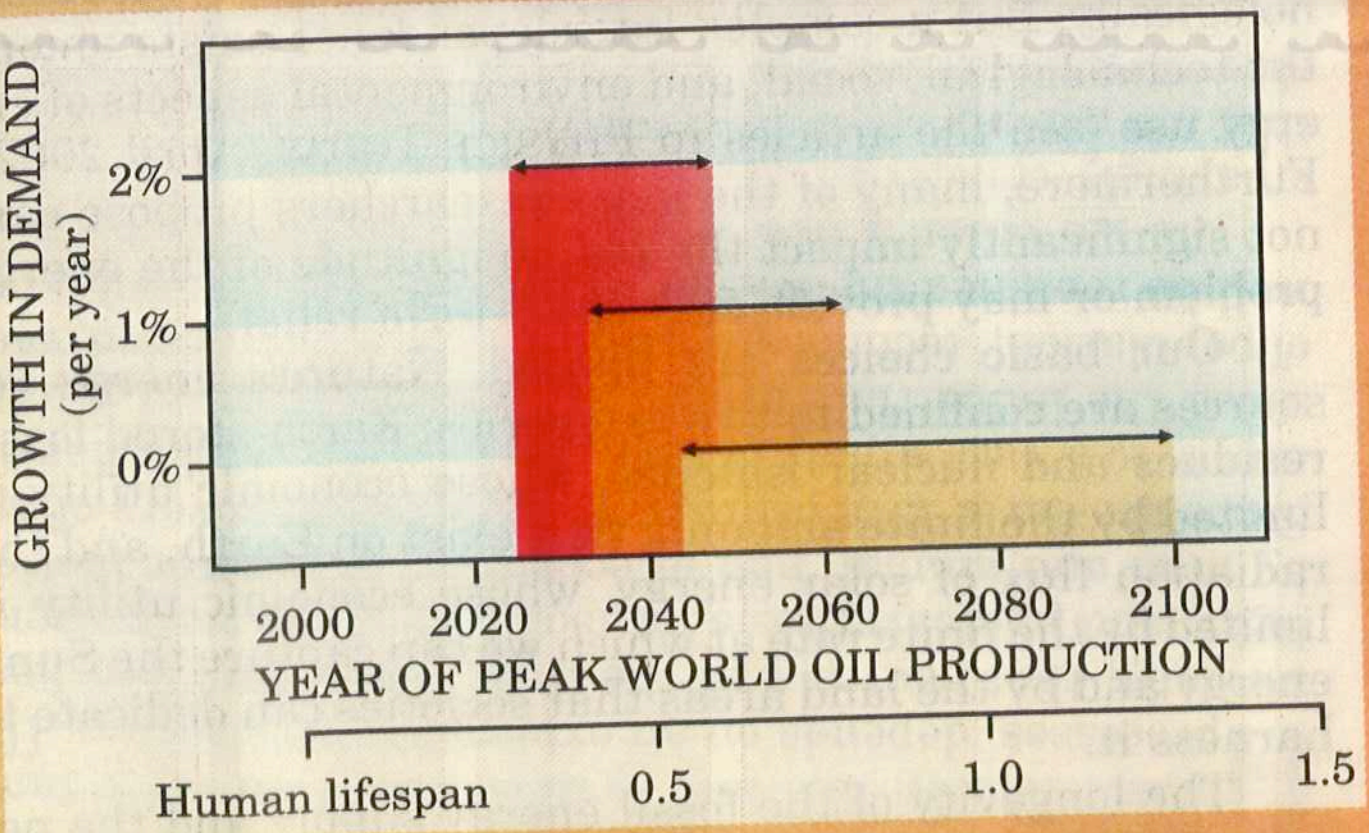
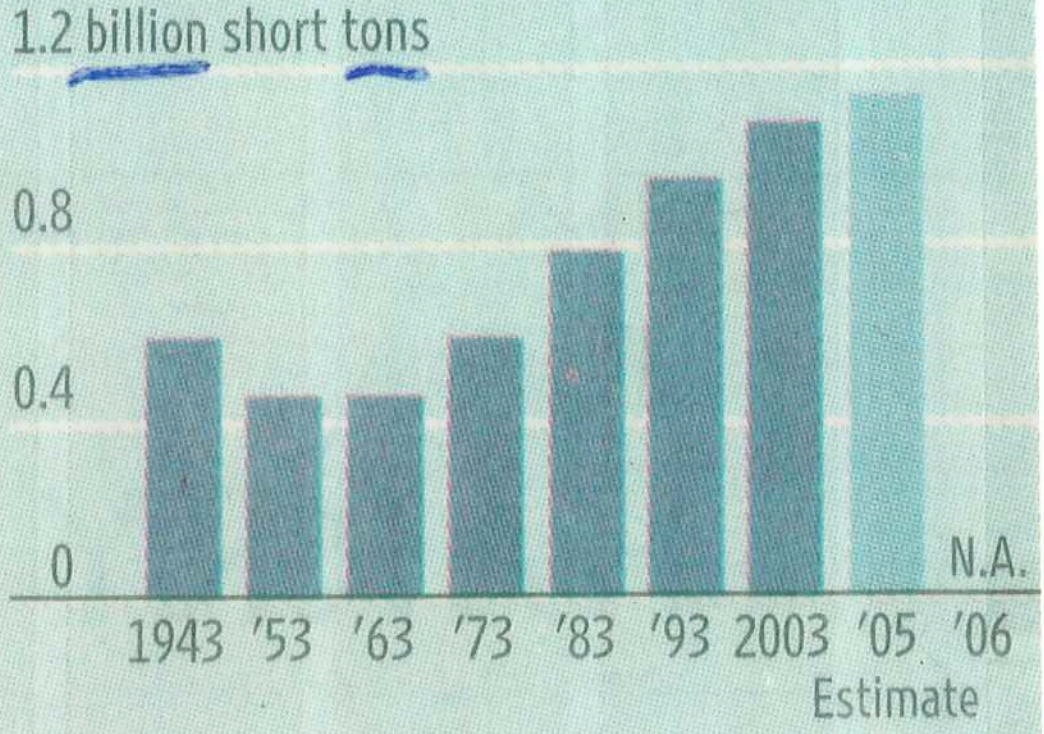


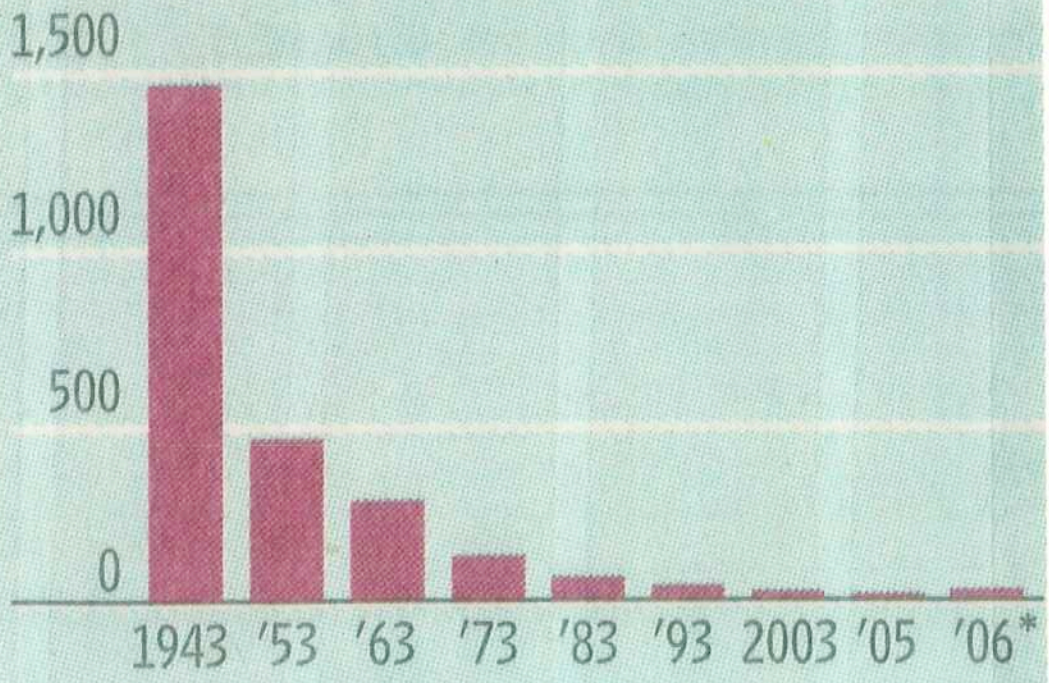
Figure 2. Predictions indicate that the peak and subsequent decline in world oil production will probably occur within the next few decades. The data here are based on optimistic estimates that place the oil reserve at 2248–3896 billion barrels. Just how soon the peak will occur depends on annual population growth rates and increases in demand. The given ranges account for uncertainty in predicting the future: For each estimate of projected growth in demand for petroleum—0, 1%, or 2%—there exists a 95% chance that the peak will occur by the year on the left-hand end of the range and a 5% chance that it may occur as late as the year on the right-hand end. (Data from ref. 4.)

Safety in Numbers

Total U.S. coal production



Total coal-mining fatalities



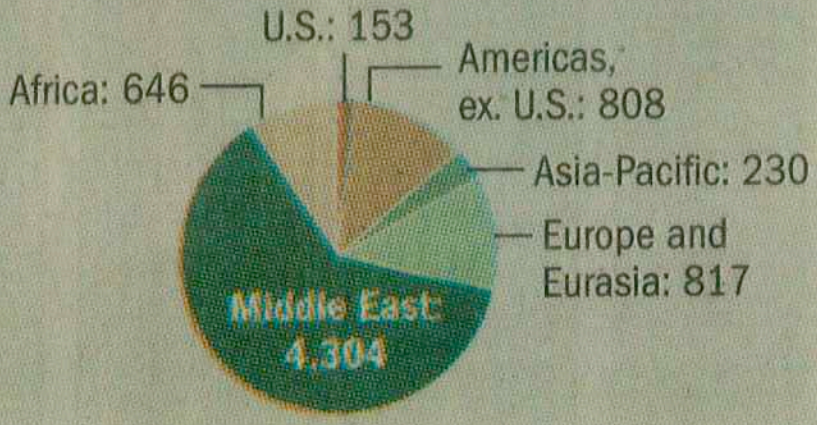
*As of May 31, 2006.

Sources: U.S. Department of Energy, Energy Information Administration; Mine Safety and Health Administration

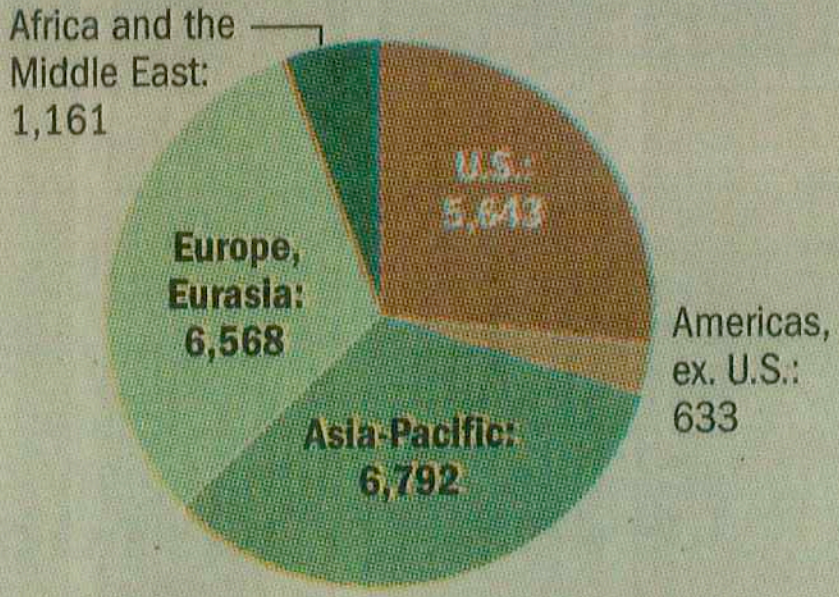
Barrels and Lumps

The U.S. has 27% of the world's coal reserves and just over 2% of oil reserves. Global proved reserves, measured by energy output:

Oil: 6,958 quadrillion BTUs



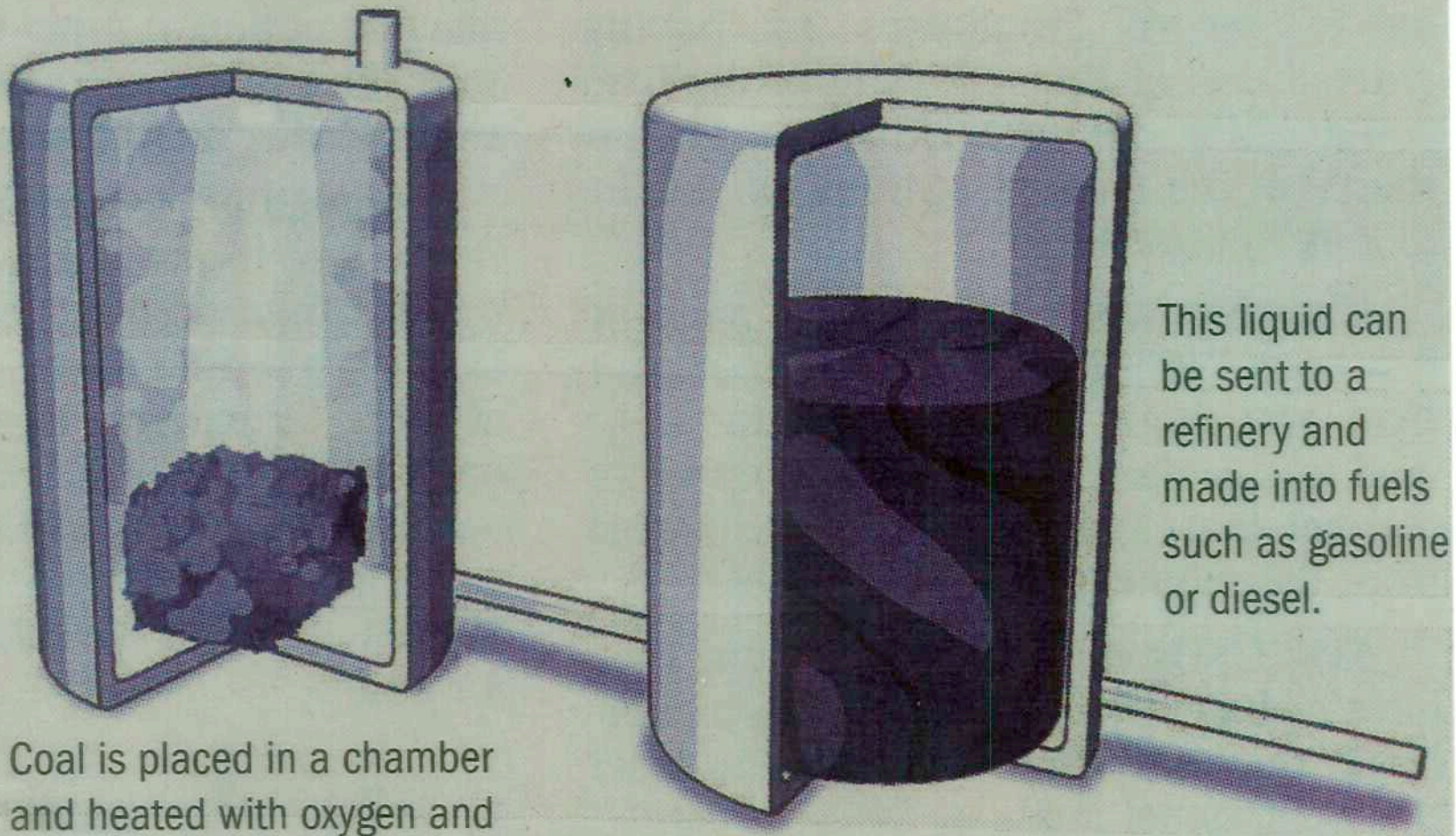
Coal: 20,797 quadrillion BTUs



Source: BP Statistical Review of World Energy 2006

From Coal to Oil

One method for creating a synthetic alternative to crude oil:



Coal is placed in a chamber and heated with oxygen and steam, creating a synthetic gas or syngas. A byproduct of this process is carbon dioxide.

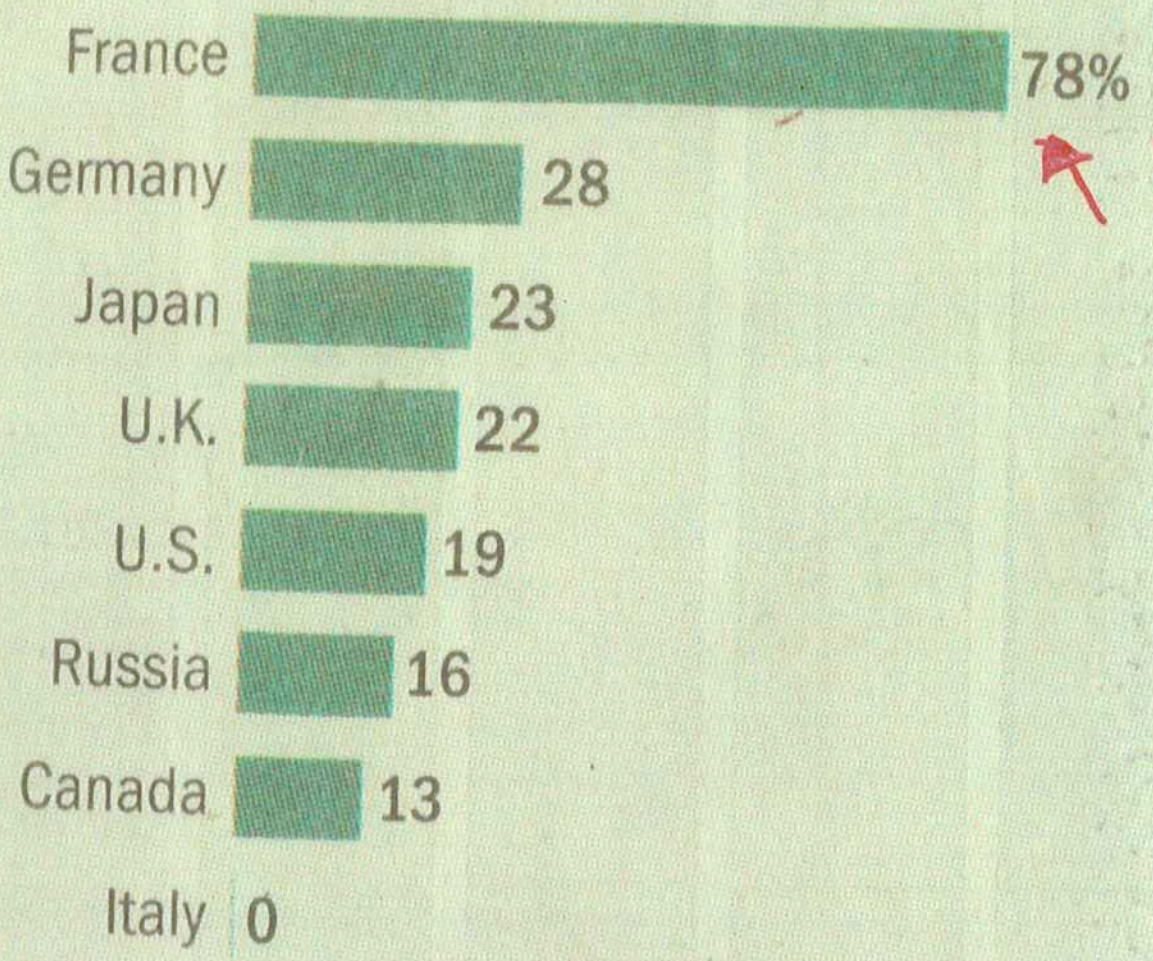
The gas is then placed in a Fischer-Tropsch reactor where heat and pressure convert it into liquid hydrocarbons.

This liquid can be sent to a refinery and made into fuels such as gasoline or diesel.

Source:
WSJ research

Power Play

Nuclear power as percentage of domestic electricity production among the Group of Eight leading nations, in 2003.



Recycle waste

Source: International Energy Agency

Generating stations

Technologies: Nuclear -- Fusion

- **The sun**
- **No commercial fusion reactors today**

Generating stations

Technologies: Nuclear – Fission

Boiling Water Reactor (BWR)

- **radioactive steam in the turbine**
- **uses enriched uranium**

WHO DOES ENRICHMENT?

COUNTRY	CAPACITY, MTSWU*	PERCENTAGE, WORLDWIDE	TECHNOLOGY
Russia	15 000	31.5	Centrifuge
United States	11 300	23.7	Diffusion
France	10 800	22.7	Diffusion
England, Germany, & Netherlands**	8300	17.5	Centrifuge
Japan	1050	2.2	Centrifuge
China	1000	2.1	Centrifuge
Brazil	**120**	**0.3**	**Centrifuge**
TOTAL	**47 570**	**100**	

* Metric ton separative work units per year for commercial-scale facilities operational and under construction.
** The three countries operate enrichment facilities through the Urenco consortium.
Source: IAEA Nuclear Fuel Cycle Information System, January 2006

WHERE IS THE URANIUM?

COUNTRY	1000S OF METRIC TONS OF URANIUM*	PERCENTAGE, WORLDWIDE
Australia	989	28
Kazakhstan	561	16
Canada	438	12
South Africa	299	8
Niger	228	6
Namibia	213	6
Russia	158	5
Brazil	**143**	**4**
United States	102	3
Uzbekistan	91	3
Other countries	315	9
TOTAL	**3537**	**100**

* Assured plus inferred resources recoverable at a cost of less than US $80 per kilogram as of 1 January 2003.
Source: OECD-NEA/IAEA "Uranium 2003: Resources, Production and Demand," 2004

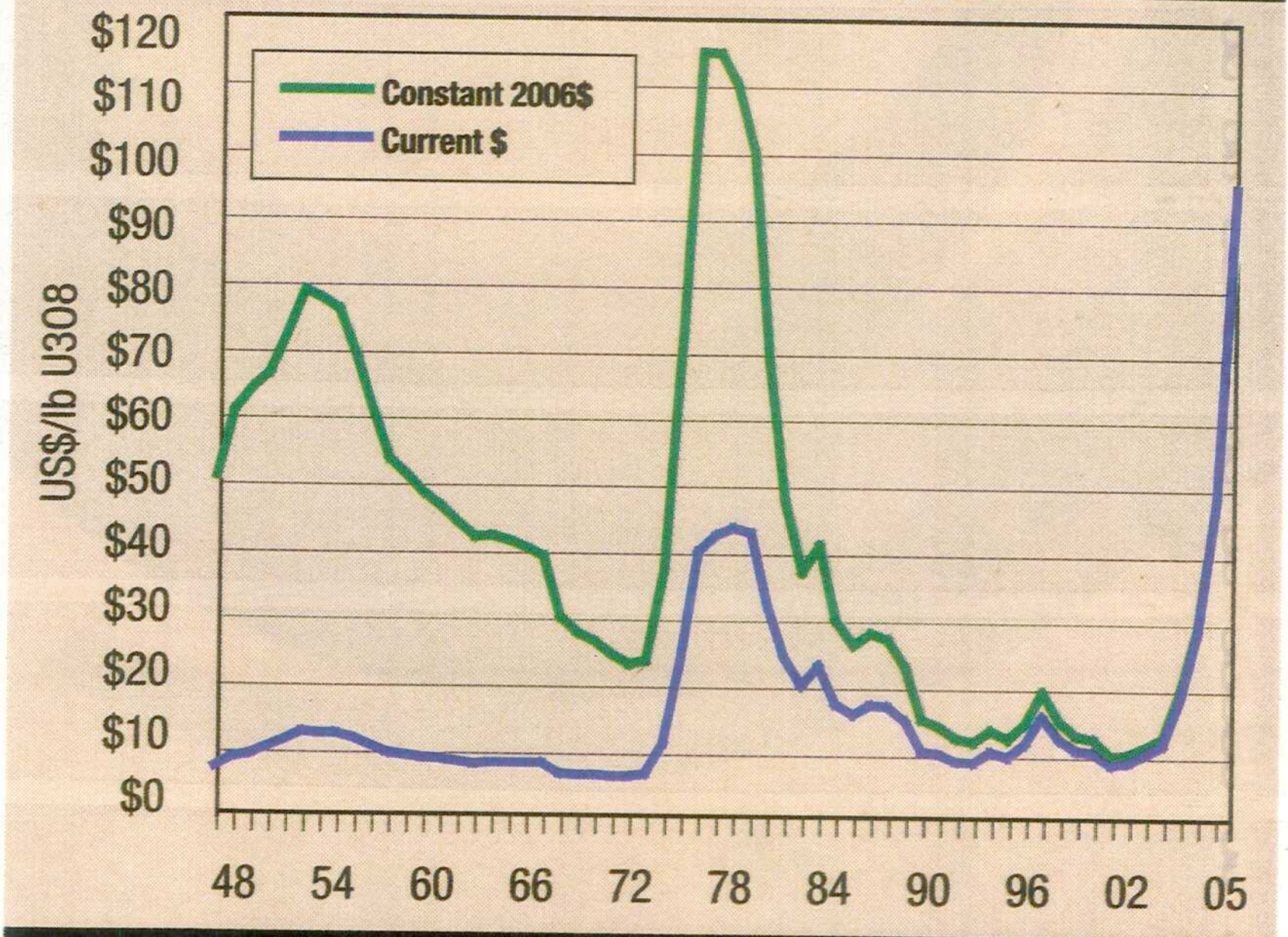
Generating stations

Technologies: Nuclear – Fission

Pressurized Water Reactor (PWR)

- **radioactive superheated water makes clean steam in steam generator**
- **uses enriched uranium**

URANIUM PRICES HAVE SPIKED BEFORE

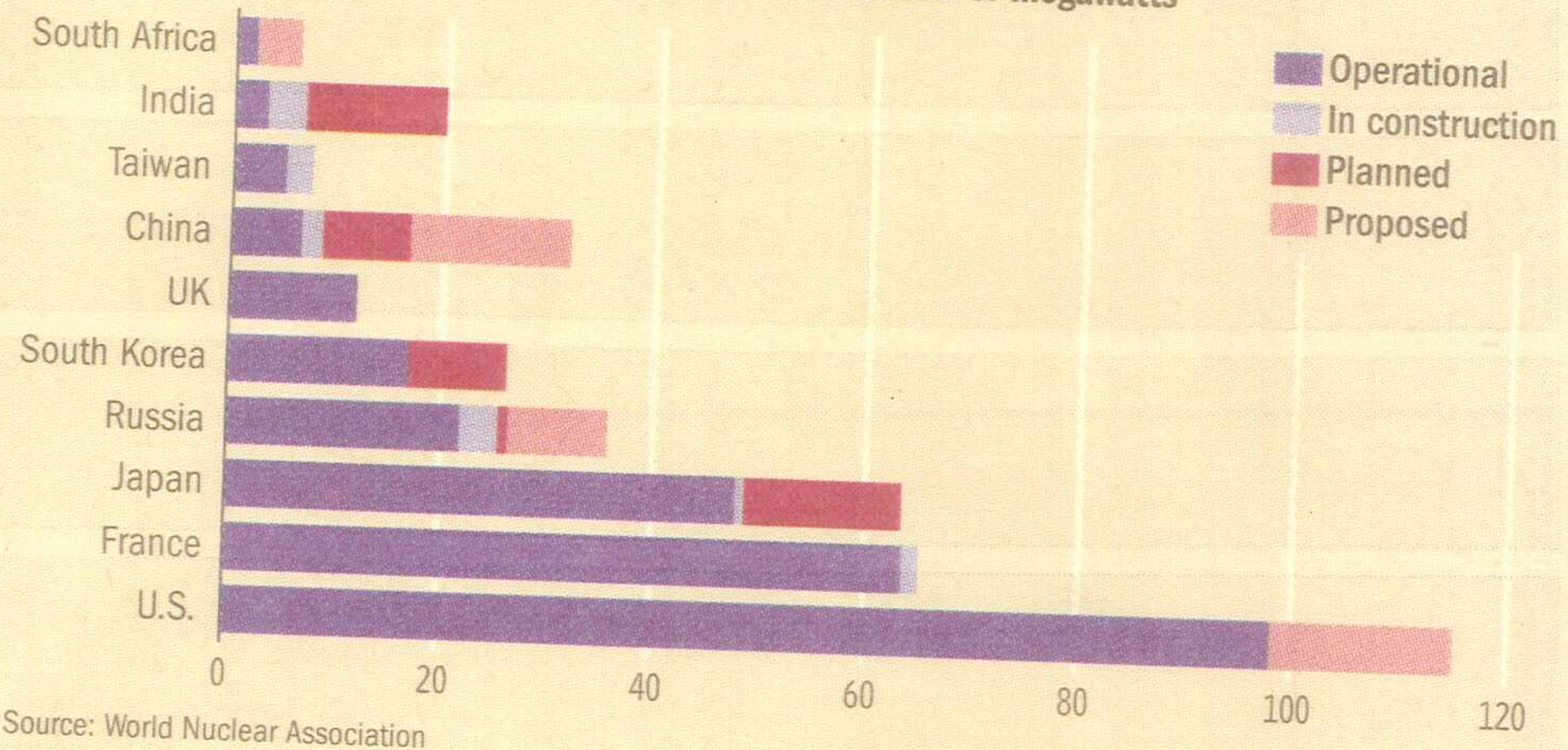


Source: UXC.com

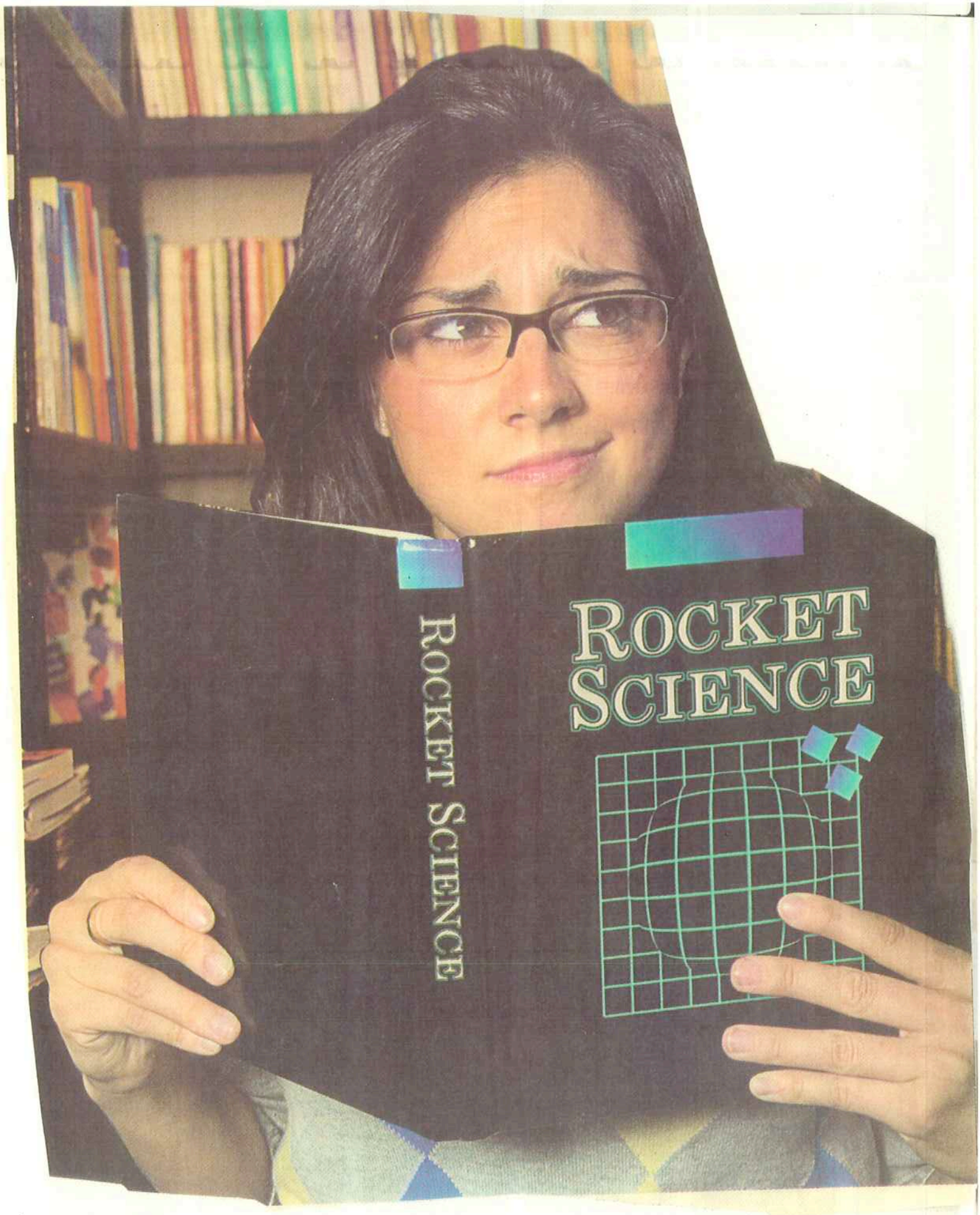
Help Wanted

Plans to build more nuclear-power plants in several countries threaten to strain the supply of expertise.

Nuclear power generation capacity by nation, in thousands of megawatts



Source: World Nuclear Association


ROCKET SCIENCE
ROCKET SCIENCE

Generating stations

Technologies: Nuclear

- **Fusion**
- **Fission**
  - **Boiling Water Reactor (BWR)**
  - **Pressurized Water Reactor (PWR)**
  - **Heavy Water Reactor (PHWR)**

Generating stations

Technologies: Nuclear – Fission

Pressurized Heavy Water Reactor (PHWR)

- **PWR that uses heavy water (D_2O : D = deuterium isotope or heavy hydrogen)**
- **uses natural uranium**

Generating stations

Technologies: Nuclear

- **Fusion**
- **Fission**
  - **Boiling Water Reactor (BWR)**
  - **Pressurized Water Reactor (PWR)**
  - **Heavy Water Reactor (PHWR)**

Generating stations

Technologies: Nuclear -- Fusion

- **The sun**
- **No commercial fusion reactors today**

Generating stations

Technologies: Nuclear – Fission

Boiling Water Reactor (BWR)

- **radioactive steam in the turbine**
- **uses enriched uranium**

Generating stations

Technologies: Nuclear – Fission

Pressurized Water Reactor (PWR)

- **radioactive superheated water makes clean steam in steam generator**
- **uses enriched uranium**

Generating stations

Technologies: Nuclear – Fission

Pressurized Heavy Water Reactor (PHWR)

- **PWR that uses heavy water (D_2O : D = deuterium isotope or heavy hydrogen)**
- **uses natural uranium**