



Sustainable Energy

Lecture 12: Hydropower

Overview of Hydropower

- Hydropower produces 20% of the world's electricity, about 635,000 MWe.
- About 103,000 MW are produced in the US; 78,000 MW is conventional hydropower, 25,000 MW is produced by pumped storage facilities.
- The ten largest power stations in the world are hydropower.



Mega-scale Hydro Projects

Table 12.1. Representative Mega-scale Hydropower Projects

Name	Location	Type	Capacity, MWe	Reservoir Size
Grand Coulee	Columbia River, Lake Roosevelt, Washington	Impoundment dam, 550 ft (168 m) high	6,480	9.4 million acre ft ^a
Niagara Falls	Niagara River, New York	Diversion, run of river	1,950	nil
Hoover Dam	Colorado River, Lake Mead, Nevada	Impoundment dam, 726 ft (223 m) high	1,500	28.3 million acre ft 146,000 acres
Norris Dam TVA	Tennessee River, Norris, Tennessee	Impoundment dam		
Glen Canyon	Colorado River, Lake Powell, Arizona	Impoundment dam, 710 ft (216 m) high	1,500	27.0 million acre ft
La Grande complex	St James Bay, Quebec, and Labrador, Canada	Impoundment, Multiple dams	10,000	9,600 km ² or about 100 Quabbins ^b
Itaipu	Paraguay/Brazil	Impoundment dam, 150 m high	12,600	
Three Gorges	Yangtze River China	Impoundment dam	17,000	
Guri	Venezuela	Impoundment dam	10,300	
Krasnoyarsk	Russia	Impoundment dam	6,000	

^a1 acre ft = 326,000 gal

^b1 Quabbin = size of the major Massachusetts reservoir system (39 square miles surface area with 12,640 acre ft. = 4.12×10^9 gal of water contained)

Resource Assessment

- We can probably triple our production of hydropower worldwide to 9,000 TWh/year.
- Canada and the US are the largest producers of hydropower in the world. China and Brazil are developing their resources rapidly.
- We can retrofit new technologies at our current facilities and increase our capacity by 35,000-70,000 MWe.



Global Capacity

Table 12.2. Global Hydropower Capacity and Investment Estimates

North America 743,187 GWh/yr	Europe 647,000 GWh/yr
South America 470,992 GWh/yr	Asia 555,000 GWh/yr
Africa 59,283 GWh/yr	Australia 39,000 GWh/yr

1,560 North American Plants (5,000 Units)

13,000 International Plants (42,000 Units)

World total capacity = 654,000 MWe

World total output = 2,517,500 GWh/Yr

World total investment = approx. \$2 trillion US total or annualized to \$50 billion/yr

Sources: World Energy Council (2001), International Commission on Large Dams, ICOLD (2001);
World Commission on Dams (2002).

Capacity by Continent

Table 12.3. Hydropower Capacity Estimates By Continent, Based on Large Dam Technology

Continent	Capacity in 2001		Maximum theoretical potential	Technically possible	Economically possible
	GWe	TWh/yr	TWh/yr	TWh/yr	TWh/yr
North America	154	743.2	6,150	2,700	>1,500
South America	99	471.0	7,400	3,000	>2,000
Africa	21	59.3	10,120	1,150	>200
Europe	210	646.9	5,000	2,500	>1,000
Asia	157	555.0	16,500	5,000	>2,500
Oceania *	13	42.4	1,000	300	>100
Total world	654	2,518	46,170	14,650	>7,300

Sources: World Energy Council (2001), International Commission on Large Dams, ICOLD (2001), World Commission on Dams (2002), and Moreira and Poole (1993).

* includes Australia and New Zealand

Potential for Development

Table 12.4. Potential for Hydropower Development in Selected Countries Based on Technical Potential and Economic Potential in Today's Energy Markets

Country	Hydro as % of total electricity	Ratio of theoretical potential to actual	Ratio of economic potential to actual
Norway	100	5.77	1.8
Brazil	91.7	5.4	3.0
Switzerland	80	—	1.1
Canada	63	3.81	1.54
India	25	4.2	3.0
France	20	1.15	1.0
China	17	10.1	6.6
Indonesia	14	31.3	3.13
United States	10	1.82	1.3
World total	19	18.34	2.78

Sources: World Energy Conference, United Nations, MIT Energy Laboratory, Paul Scherrer Institute.

Basic Energy Conversion Principles

- There are 3 types of hydropower systems:
 - Impoundment
 - Diversion
 - Pumped Storage (this system uses excess power production to store energy for future use).
- Turbine-generator efficiencies can approach 0.9 for large flow machines.

Impoundment Hydro

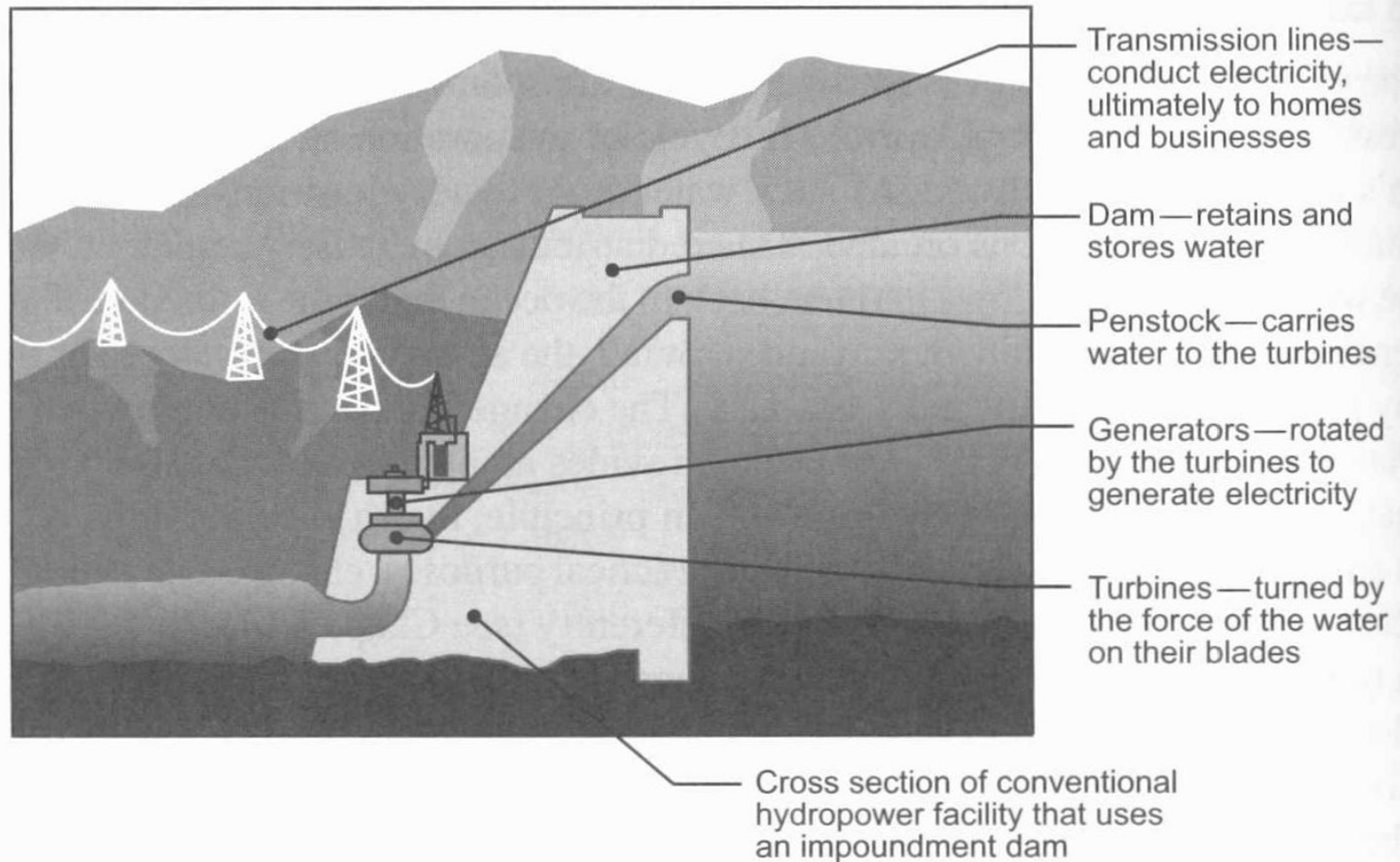
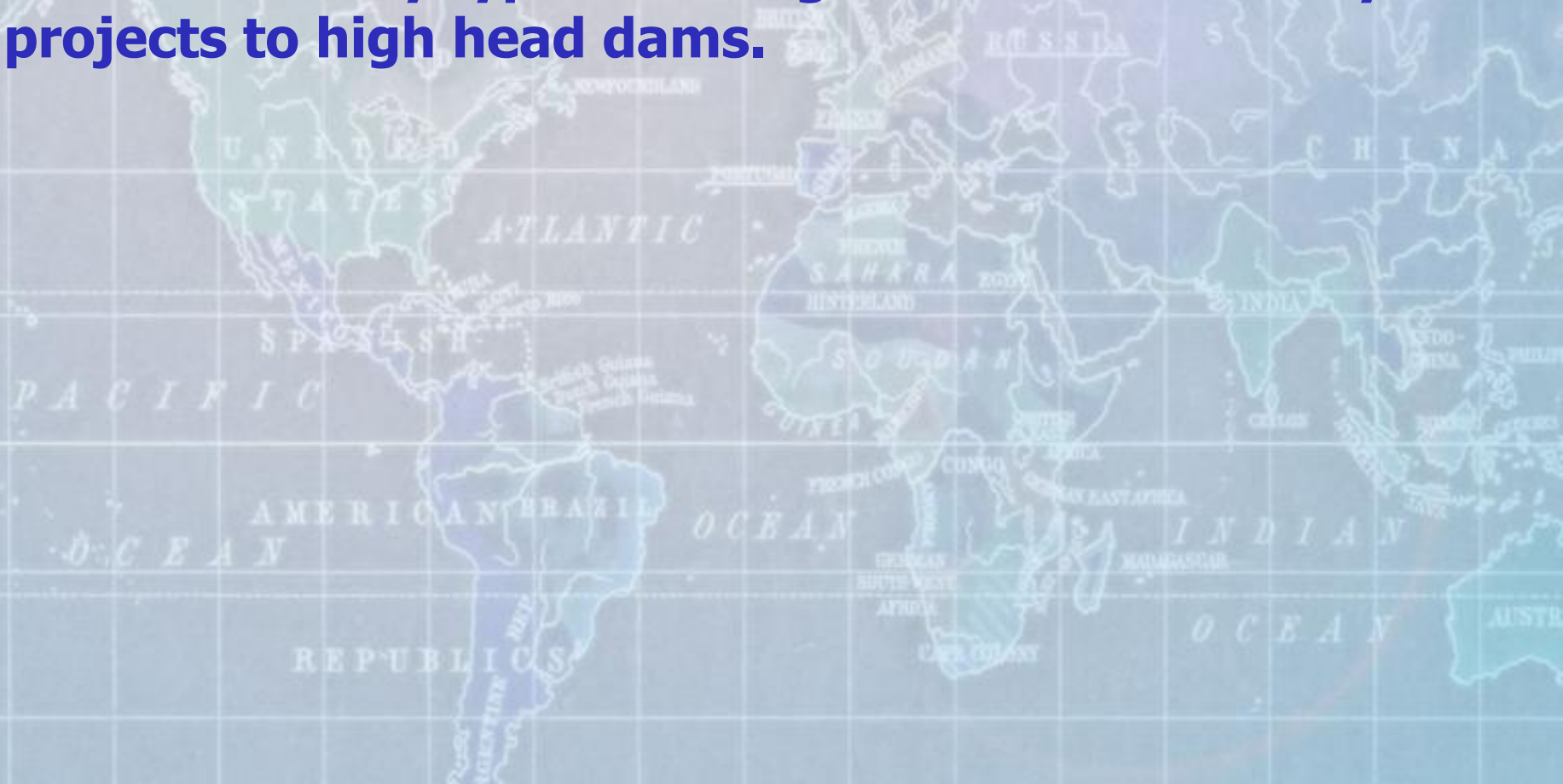


Figure 12.1. Schematic of a typical impoundment type hydropower installation.
Source: INEEL (2003).

Conversion Equipment

- Several types of turbines are used in hydropower dams.
- The hydraulic head and volumetric flow rate are the primary variables effecting power production.
- There are many types of designs from low head hydro projects to high head dams.



Sustainability Attributes

- **Hydropower uses a renewable resource.**
- **Hydropower can aid in seasonal water management.**
 - Irrigation water
 - Flood Control
 - Human consumption
 - Recreational activities
- **Hydropower projects have been argued to improve the local economies of developing regions.**
- **Environmental Concerns:**
 - **Effects on riverine ecosystems.**
 - Flood pulse is removed.
 - Migration patterns can be interrupted.
 - Habitat destruction.
 - **Effect on local/indigenous populations.**
 - Diseases: malaria, filariasis, schistosomiasis (river blindness)
 - Agricultural impacts.
 - Displacement and cultural impacts.
 - **Seismic risks/dam failures.**

Hydropower Today

- **Hydropower displaces a significant amount of carbon dioxide emissions.**
- **Hydropower has low maintenance costs and long lifetimes.**
- **In the US the DOE estimates capital costs for an average sized hydro plant (31 MW) from \$1700-2300/kW; annualized to about 1.8 cents/kWh; maintenance at 0.8 cents /kWh.**
- **Environmental concerns in the US have slowed down new construction.**
 - **Fish mortality in turbines.**
 - **Oxygen depletion in discharge water.**
 - **Upstream migration issues.**

New low head hydro technology may allow expansion of the industry