DESIGN ASPECTS AND SUSTAINABILITY OF MINI/MICRO HYDROPOWER SCHEMES

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EAST AFRICAN REGION AFRETEP PROJECT WORKSHOP
An European Commission training initiative for experts in energy
Kampala, Uganda: 03-07 October 2011

SUB-TOPICS

- MHP systems overview
- SHP design and development
- Sustainability aspects
- Policy and regulatory issues
- Financing issues
- Case studies/success stories

SHP SYSTEMS OVERVIEW

MAIN FEATURES OF MHP

- Empowerment
- Local participation and decision making
- Equity
- Flexible local contribution in cash or kind
- Construction by community
- Comprehensive training for selected village youth
- Sustainability
- Livelihoods

ROLE OF SHP IN DEVELOPMENT

- Improving quality of life:
  - Light, Drinking Water Supply Health and Sanitation, etc
- Supplementing Traditional livelihoods:
  - Irrigation, Adding value to local produce, etc
- Opening New Avenues of Employment:
  - Tourism, Eco-tourism, processing non-wood forest produce, IT, Marketing etc
- Conserving Forest and Environment:
  - Promoting use of Power at Household level

SHP DEFINITIONS

UK	≤	5 MW
UNIDO	≤	10 MW
India	≤	25 MW
Sweden	≤	15 MW
Colombia	≤	20 MW
Australia	≤	20 MW
China	≤	25 MW
Philippines	≤	50 MW
New Zealand	≤	50 MW
Iran	≤	10 MW

SHP CLASSIFICATION

Capacity ranges

Pico	≤ 5 kW
Micro	≤ 100 kW
Mini	≤ 1MW
Small	≤ 10MW

Head ranges

High	75 m & above
Medium	30-75 m
Low	3-30 m
Ultra low	below 3 m

PROS AND CONS OF MICRO-HYDRO

Pros

- **Efficient energy source**
  - Takes little water
  - Allows substantial distribution
- **Reliable electricity source**
- **No reservoir required**
- **Cost effective energy solution**
- **Power for developing countries**
- **Integrate with the local power grid**

PROS AND CONS OF MICRO-HYDRO . .

Cons

- Suitable site characteristics required
- Energy expansion not possible
- Low-power in the dry period

MISCONCEPTIONS ON MICRO-HYDRO

- Small streams do not provide enough force to generate power
- A large water reservoir is required
- Hydro generators will damage the local ecosystem
- Micro hydro electricity is unreliable
- The electricity generated is low quality
- Hydro power is free

COMMON TERMINOLOGIES

Installed Capacity	The total maximum output (kW) of the generating units in a hydropower plant.
Kilowatt (kW)	Unit of power, equal to 1000 watts
Kilowatt hour (kWh)	Unit of electrical energy, equal to the electricity supplied by 1 kW working for 1 hour. 1 kWh = 3,600,000 Joules
Leat or Lade	An open channel that conveys water at a shallow gradient from a river channel where sufficient head has been gained for a turbine to be installed. (Also sometimes called Goit or Contour Canal).
Net Head	The pressure head available to the turbine after friction losses through the intake and trash rack.
Output	The amount of power (or energy depending on definition) delivered from a piece of equipment, station or system.
Penstock	A pipe (usually steel, concrete or plastic) that conveys water under pressure from intake to turbine.
Sluice Gates	A vertical shaft slide gate, which can be operated either manually or by electric motors (there are other types).

COMMON TERMINOLOGIES . .

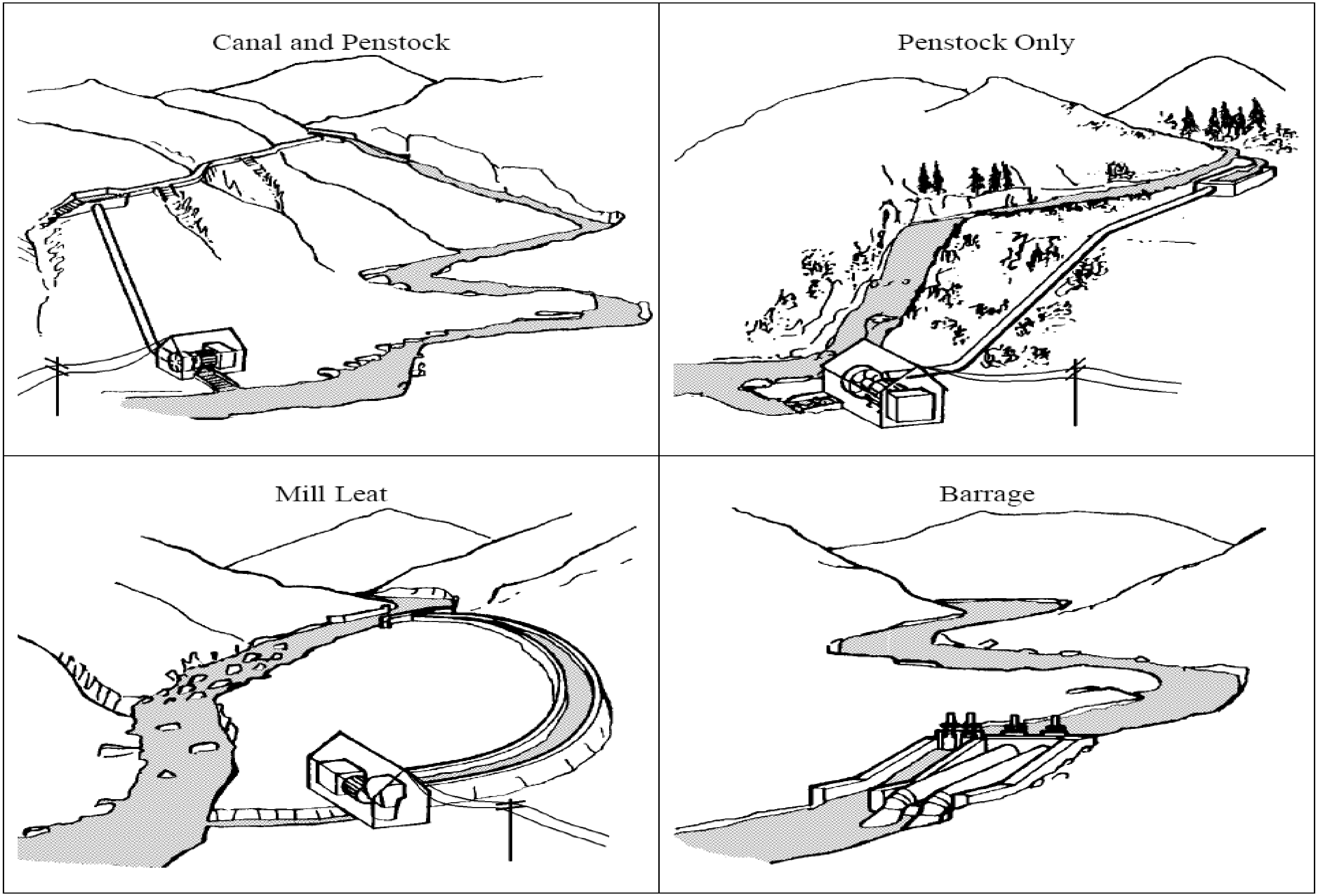
Capacity factor (also called 'Load Factor')	The ratio of energy output per year to the maximum output if the system runs at full rated capacity all year round.
Compensation Flow	The flow which must be left in the river at the point of abstraction, for ecological purposes.
Fish Ladder (or Fish Pass)	A structure consisting of a series of overflow weirs which are arranged in steps that rise about 30cms in 3 to 4m horizontally, and serve as a means for allowing migrant fish to travel upstream past a dam or weir.
Flow Duration Curve	A graph showing the percentage of time that the flow at a particular gauging station equals or exceeds certain values.
Forebay	An open tank for slowing down the incoming flow and settling out silt and gravel before the flow passes into the penstock.
Gauging Station	A site where the flow of a river is measured.
Gross Head	The difference between the upstream and downstream water levels.
Headrace	The channel that forms the inlet to a turbine.

COMMON TERMINOLOGIES . . .

Spillway	A controlled discharge of excess flow back into the river.
Tailrace	The channel that takes flow away from the turbine outlet
Trashrack	A protective screen that prevents large branches, tree trunks and other debris from entering and damaging the turbine. It usually consists of vertical bars spaced between 30-100 mm apart. The screen is typically cleaned by an automatic rake which removes the debris, either to a platform or to be flushed into the river.
Turbine	A machine converting the speed and/or pressure of flowing water into rotational energy.
Weir	A low dam which is designed to provide sufficient upstream depth for a water intake while allowing flow to pass over its crest.

BASIC COMPONENTS OF SHP

* Civil Works
  - Intake/Diversion Weir.
  - Power Channel.
  - Desilting Tank.
  - Forebay Tank.
  - Penstock.
  - Power House Building.
  - Tail Race.
* Electromechanical Equipment
  - Turbine.
  - Generator & Controls.
  - Power transmission & distribution network


Canal and Penstock
Penstock Only
Mill Leat
Barrage

BASIC COMPONENTS OF SHP - CIVIL STRUCTURES

Diversion Weir

De-silting Tank

Canal Headrace

Forebay Tank

Penstock Route

Power House

BASIC COMPONENTS OF SHP – ELECTROMECHANICAL EQPT

Turbine, generator & Control panel

Power evacuation

CHOICE OF THE SITE

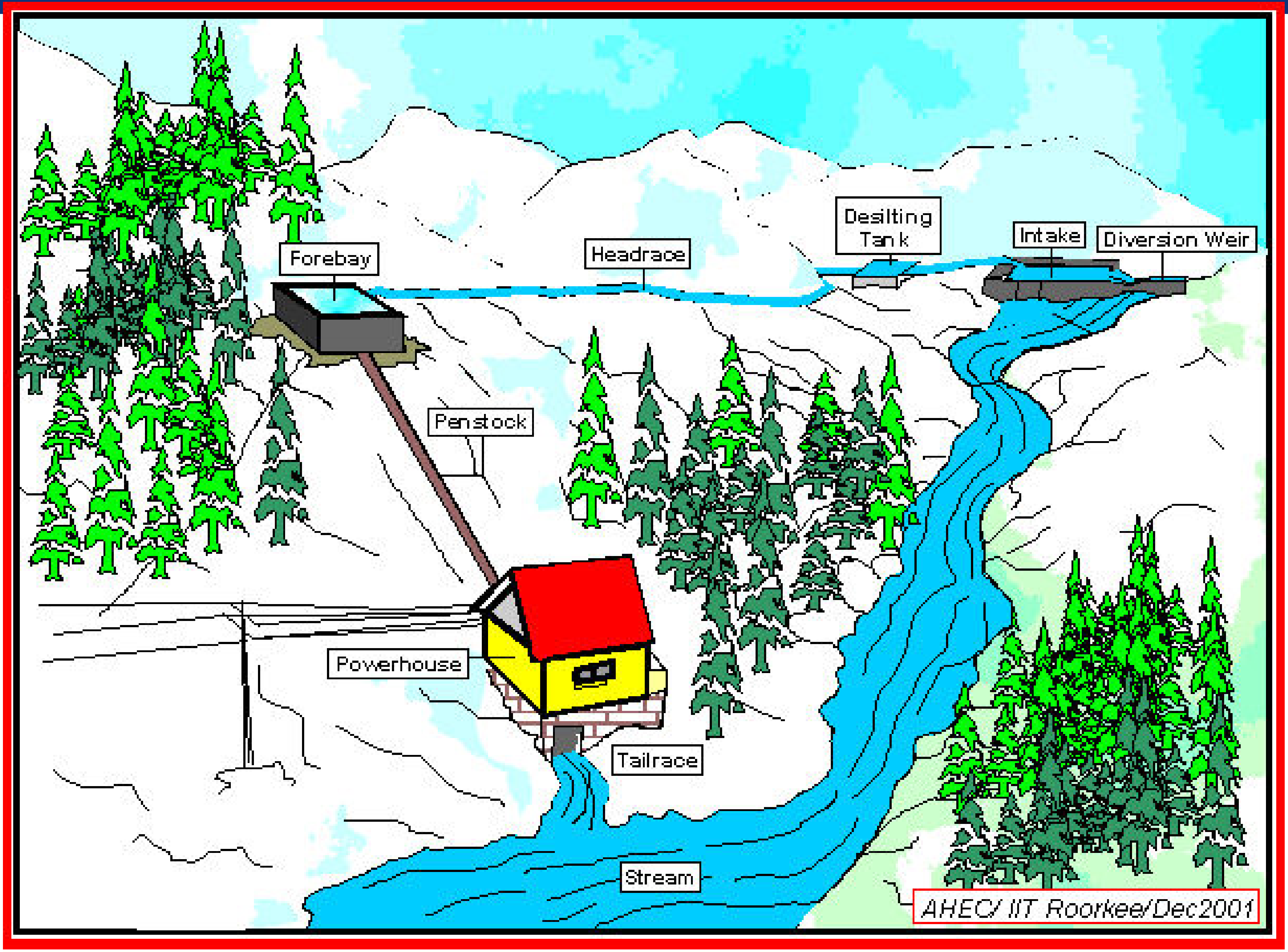
- Location and Accessibility of Site
  - It is preferable to select the site near the load centre and convenient for access. In the first place we relocate these sites on small scale map, and then proceed with reconnaissance.
- Condition of Water Resources
  - This is most vital factor to determine whether or not the site is feasible. It is important to locate the project on a river with abundant (or sufficient) runoff and having stable base flow (a perennial river) is careful to avoid setting MHP station on an intermittent stream.
- Topographical Conditions
  - This may influence mostly the construction cost of MHP. We should take the advantage of the narrow water (canyon or gorge), natural fall, chute, river bend, bifurcation and interbasin development to get higher water head with less amount of engineering.

CHOICE OF THE SITE . .

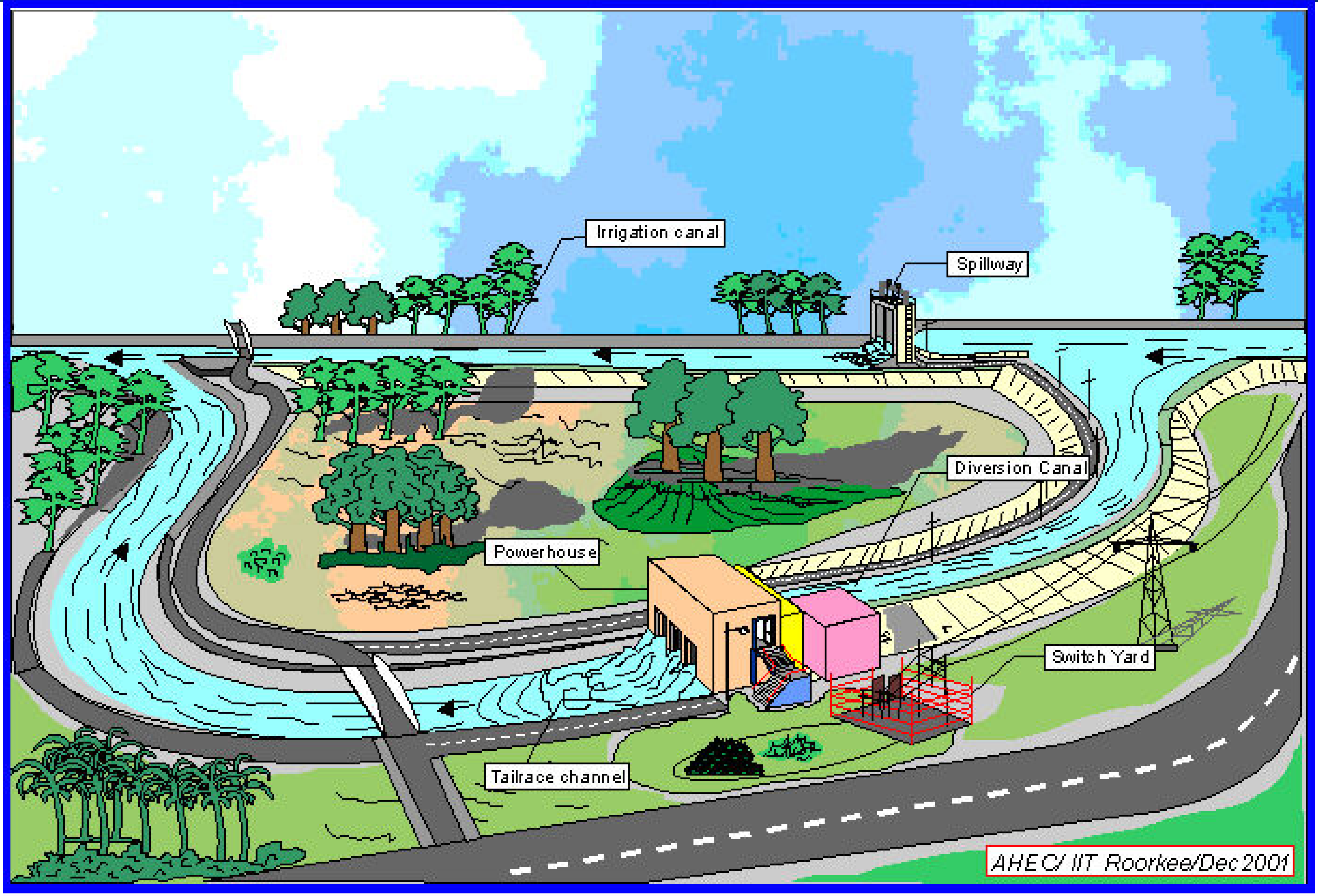
- Geological Condition
  - Geological condition may rank second to topographical for MHP. Special attention should be put
  - in the foundation of intake weir, open canal, forebay and powerhouse. Landslide is main risk for MHP projects
- Multipurpose Utilization
  - This may command the site selection when irrigation or other water users are in urgent need.
  - In this case, careful balance of the runoff for different utilities is important.
  - River Planning, Cascade Development of Small River. It is better to select a site coinciding with the overall river planning or cascade development, i.e the selected site is just one of the planned cascades. One of following cases should be avoided: the selected site is just located in the reach of backwater of future reservoir, or the site would be eliminated in the near future when hydropower projects have been built.
- Local Materials
  - Making use of indigenous raw material for civil engineering is a principle for MHP construction, it will greatly reduce the project cost.

TYPES OF SHP SCHEMES

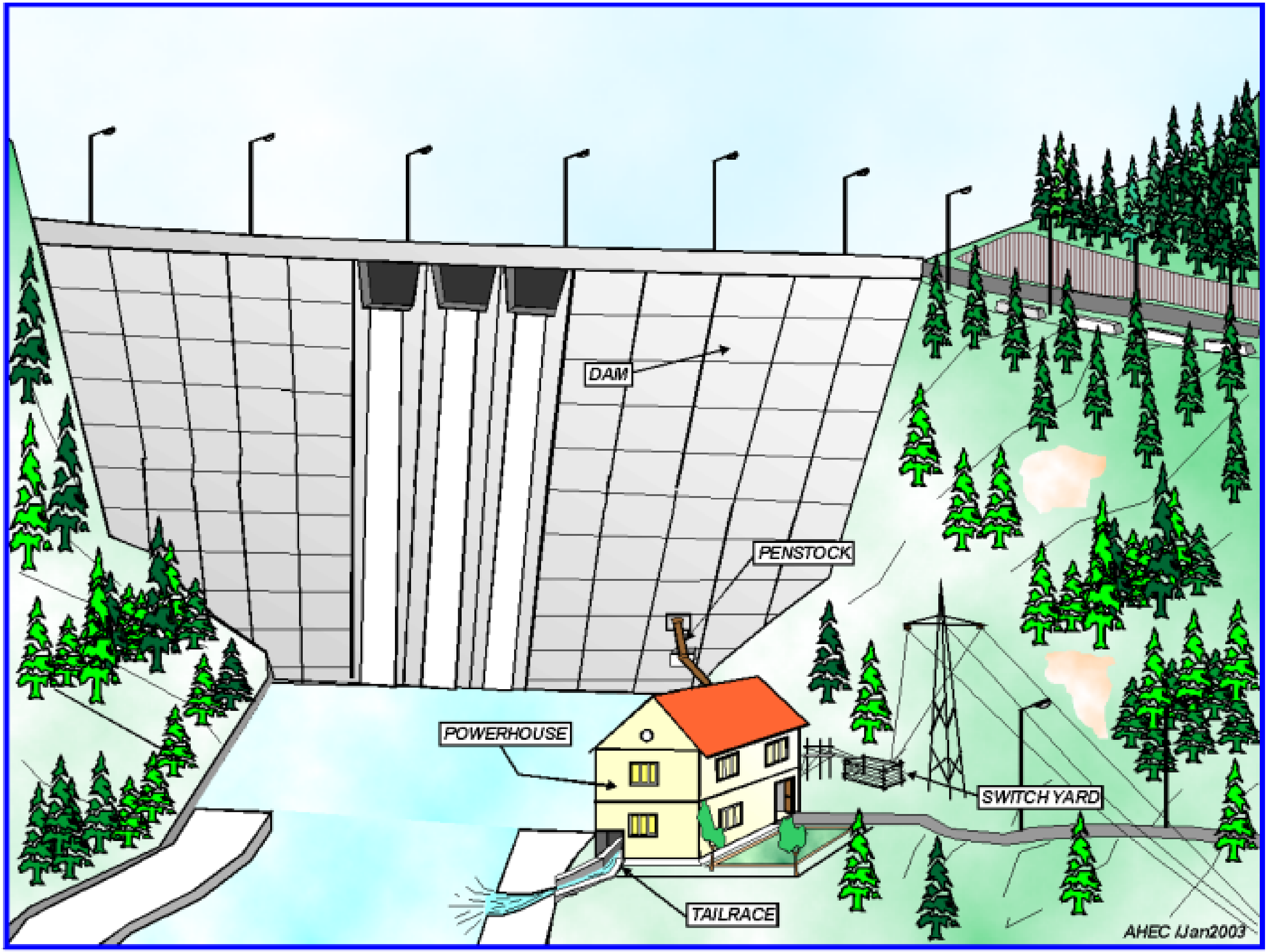
- **Run-of-river**
- **Canal fall based**
- **Dam Toe based**



Typical Arrangement of Small Hydro Power Station



Typical Arrangement of Canal Fall Small Hydro Power Station



Typical Arrangement of Dam toe Small Hydro Power Station

POWER POTENTIAL AND GENERATION

Basic Equation for Power

Power in kW = Q.H.9.81.n

Where, Q Discharge in m^3

H Head in metres

n Overall efficiency of turbine, gear-box & generator

The annual energy generated is computed from the flow, flow duration curve or energy equation:

E = t.p

= n.g.H [kWh/year]

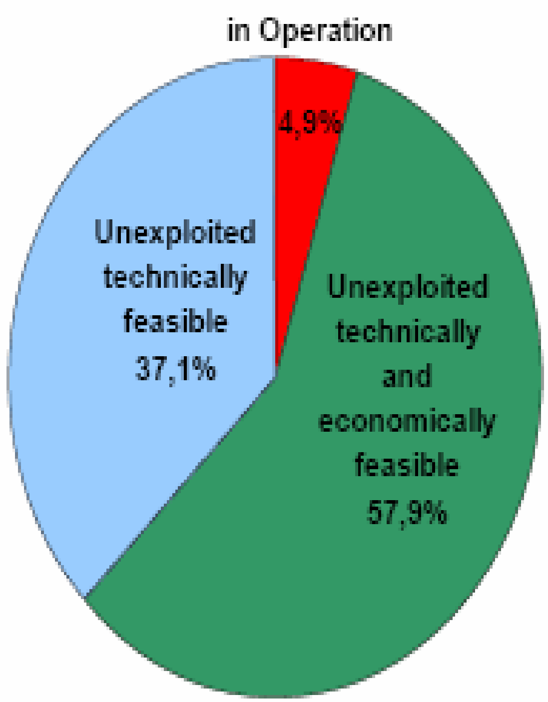
Where t = time in hours (8750 per year)

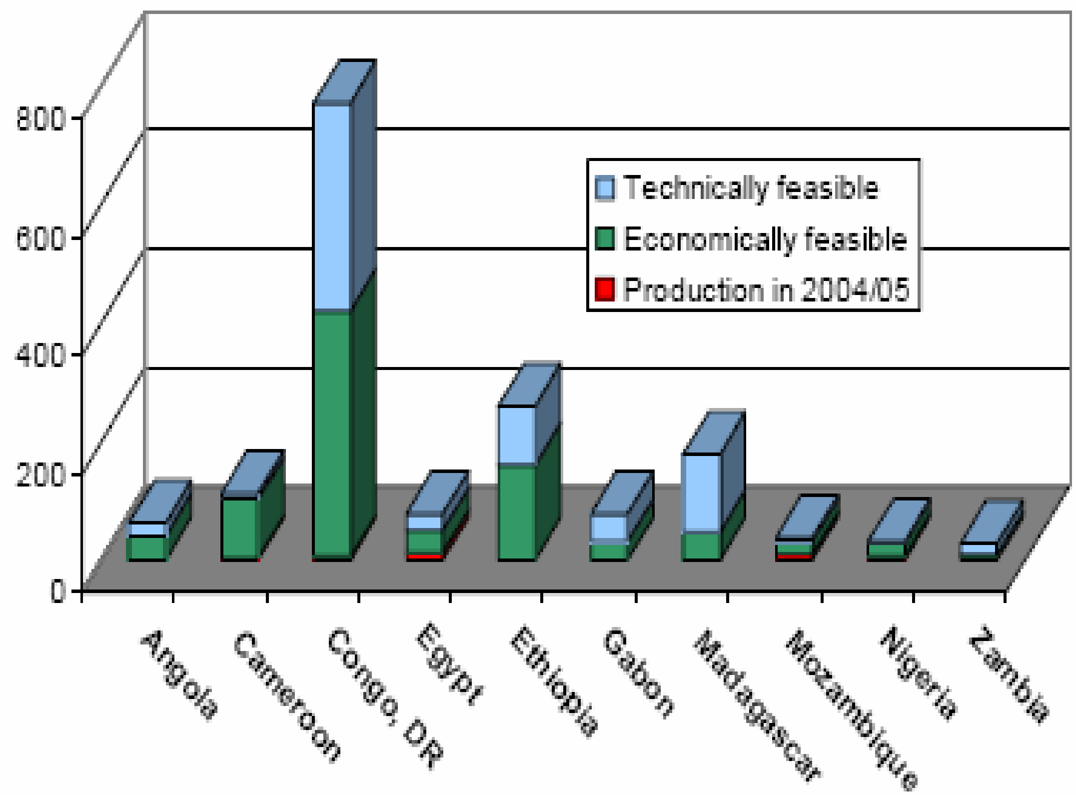
GLOBAL POTENTIAL AND UTILISATION

Continent / Country	Potential Theoretical TWh/Year	Installed Capacity GW	Hydro Supplies %	Planned Hydro GW	Under Construction GW	Small Capacity GW	Percentage of small w.r.t large hydro
Africa	1750	20.92	> 50	77.5	3.024	0.333	1.59
Asia	6800	244.8	> 50	1.75	72.70	0.343	0.14
Australia	200	13.20	> 50	0.65	0.177	0.102	0.77
Europe	1035	177.4	50	10	2.27	9.50	5.36
North & Central America	1663	157.7	> 40	15	5.79	4.302	2.73
South America	2700	114.4	> 50	59.5	16.75	1.113	0.97
China	1920	82.7	> 17	50	35.00	30.51	38.00
India	660	28.50	> 25	37	5.27	1.50	5.26

HYDRO POTENTIAL IN AFRICA

African Hydropower Potential	
Total African Potential: 1.750 TWh	Data for Top 10 Countries in TWh



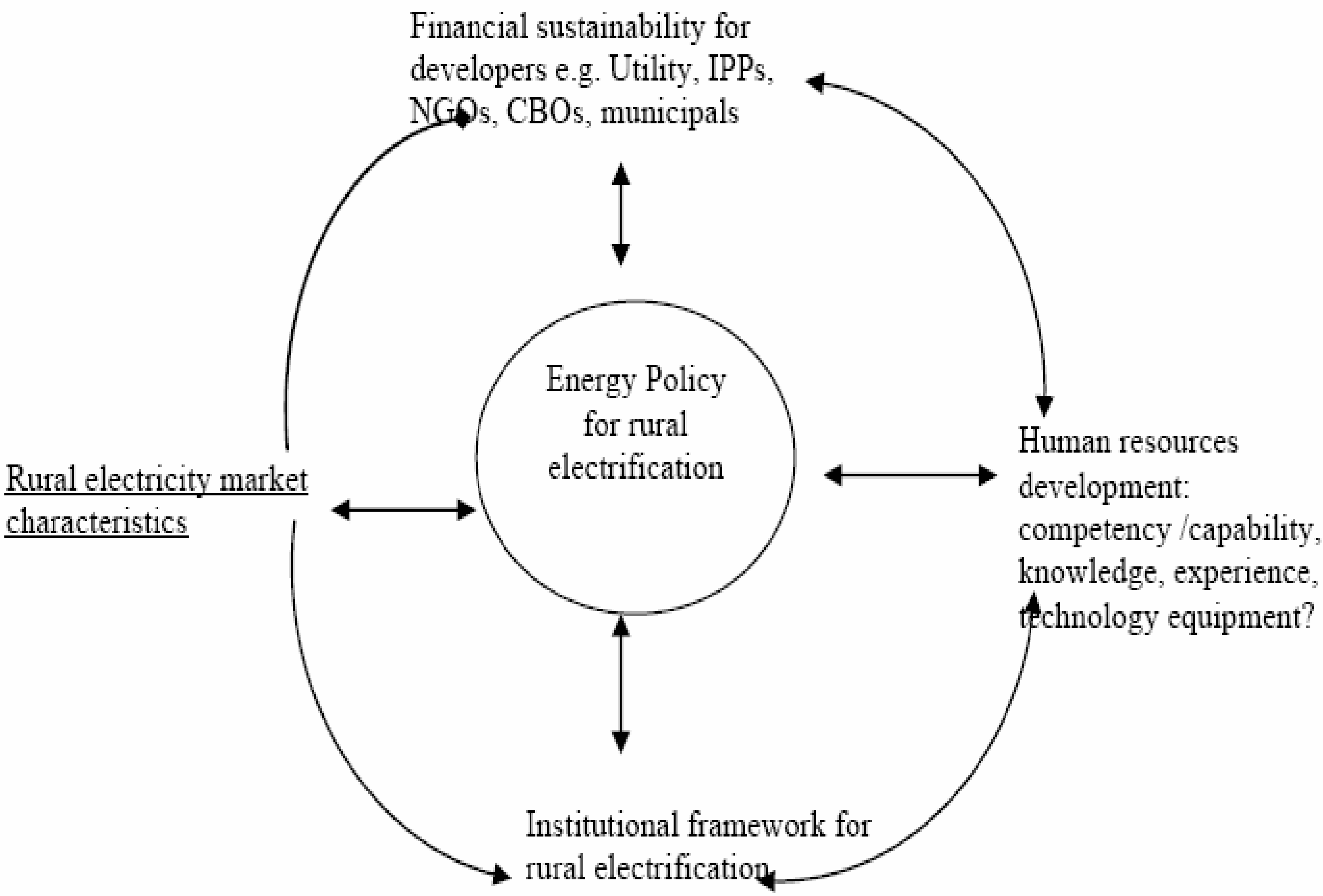


CHALLENGES INHERENT TO SHP DEVELOPMENT

The key barriers hindering the development of SHP in Africa can be summarised as follows:

- Lack of infrastructure in the design and manufacture of turbines, installation and operation
- Lack of access to appropriate technologies pico, micro, mini and small hydropower. Networking, sharing of best practices and information dissemination through forums and conferences
- Lack of local capacity (local skills and know how) in developing SHP projects. There is the need for technical assistance in the planning, development and implementation
- Lack of information about potential sites (hydrological data)
- Lack of SHP awareness, incentives and motivation
- Lack of private sector participation in SHP development.
- Lack of joint venture (public and private sector partnership)

CHALLENGES INHERENT TO SHP DEVELOPMENT



Kato T. Kabaka and Florence Gwang'ombe, TANESCO

MINI/MICRO-HYDRO SCHEME DESIGN AND DEVELOPMENT

SHP PROJECT DEVELOPMENT STAGES

- Reconnaissance/pre-feasibility study
- Feasibility study (including EIA where applicable)
- Project construction
- Project operations

ESTIMATED STUDY LEVELS

s/n	Item	Commercial Project above 500 kW	Social Sector Project below 500 kW
1.	Reconnaissance Level report	yes	yes
2.	Pre-feasibility Report	Yes 3 months	yes 2 months
a	Detailed Investigations	Yes 4-12 months	Limited 1-3 months
b	Feasibility Report	Yes 6 months	Not required
c	Financial Approval	yes	yes
d	Detailed Construction drawings and technical specifications	Yes 3-6 months	Limited 1- 2 months

CAPABILITY AND DEMAND SURVEY

- How much energy is needed.
- For what purpose and in what form e.g. Mechanical, heat, electricity
- Are members of the community willing and capable of paying for the proposed supply
- What economic and social activities will the project stimulate e.g. Food processing, potable water distribution, small cottage industries, etc.
- Disadvantage of system e.g. Loss of jobs, etc. If any.
- Will the scheme be effectively managed over a long period (say 15years)
- What capability and /or past experience exist for effective management
- Organization of tariff collection, keeping financial accounts, resolving conflicts, etc.
- What further assistance is required to raise capability to required level, if any.

ELECTRICAL LOADS

1. RESIDENTIAL POWER. (BASED ON KW LOADS PER HOUSEHOLD)

A.	LIGHTING:	393 X. 2KW	=	78.6KW.
B.	REFRIGERATION:	208X.3KW	=	62.4KW
C.	IRONING:	236 X .5KW	=	118. 0KW
D.	RADIO/TV (ELECTRONIC):	399X 0.2	=	79.8KW
E.	WATER PUMPING:	10 X 0.7	=	7.0KW
F.	FANS:	393 X 0.1KW	=	39.3KW
	TOTAL			383.9KW

2. INDUSTRIAL POWER:

AGRO- PROCESSING:	5X3. 0KW	=	15KW

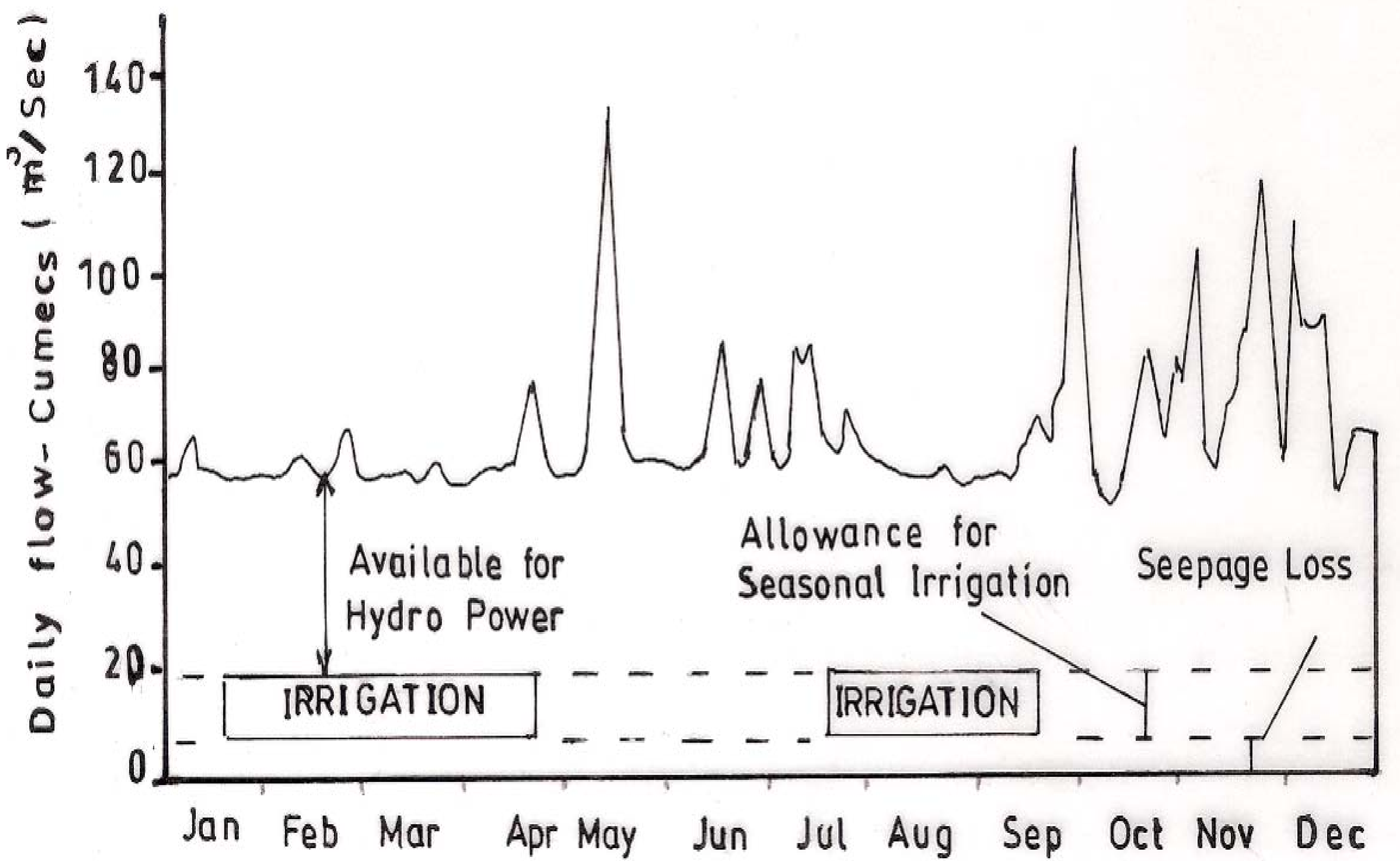
3. COMMERCIAL POWER.

LIGHTING:	24X0.2KW	=	4.8KW
REFRIGERATORS/FREEZERS:	24X0.3	=	7.2KW
FANS:	24 X0.1KW	=	2.4KW
TOTAL			**14.4KW**

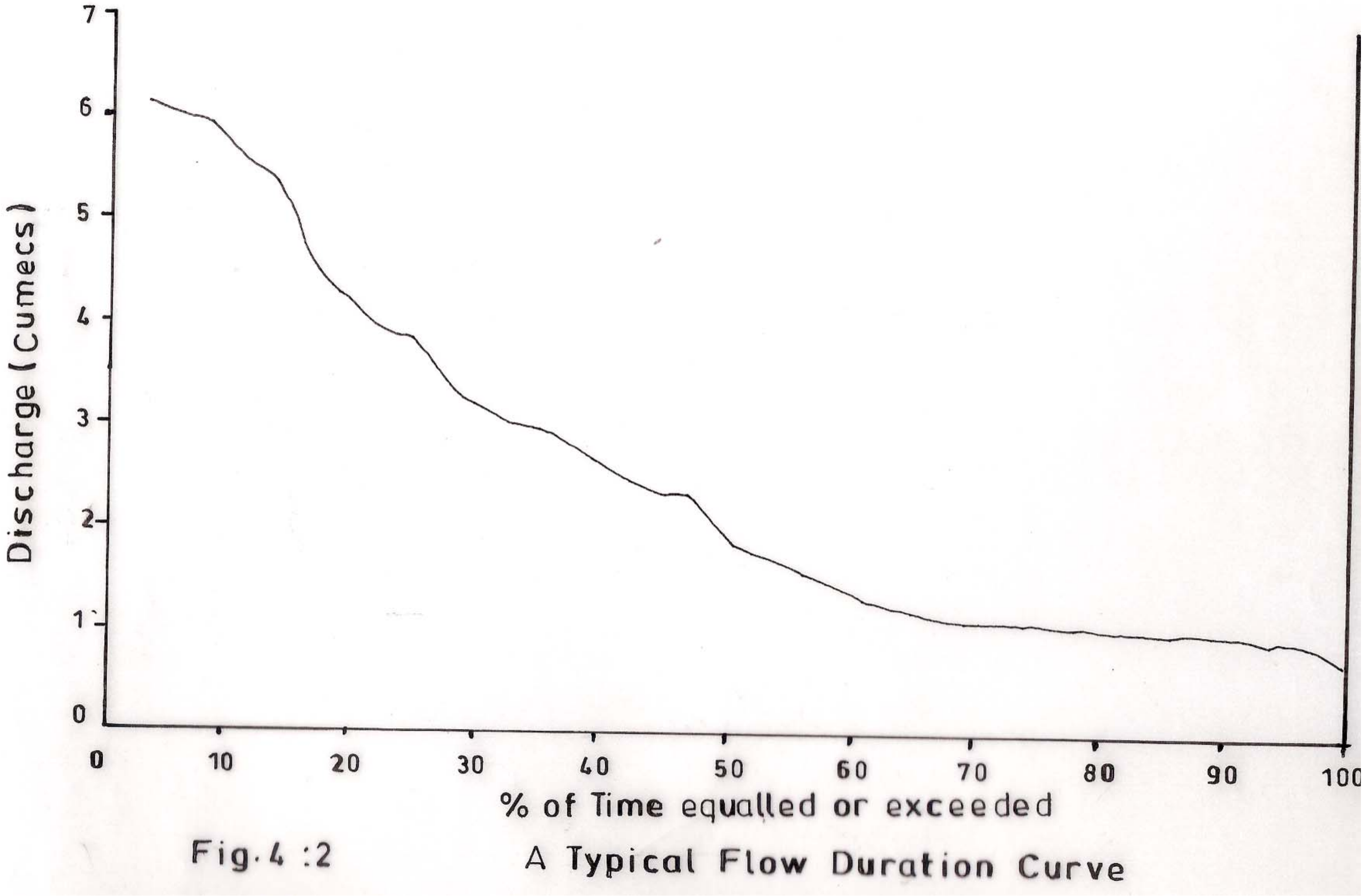
GRAND TOTAL
RESIDENTIAL == **383.9KW**
INDUSTRIAL == **15.0KW**
COMMERCIAL == **14.4KW**

HYDROLOGICAL STUDIES

- The purpose of a hydrological study is to predict the variation in the flow during the year
  - Annual hydrograph, and
  - Flow Duration Curve (FDC)



Annual Hydrograph



Flow Duration Curve

FEASIBILITY STUDIES

A detailed study containing:

- **Energy demand;** as discussed under Capability and Demand Survey
- **Water Demand**
- **Future Demand Trend**
- **Energy Supply Options;** involves a brief survey and costing tables of various energy inputs including traditional fuels currently in use. Comparative costing of energy sources which are alternatives to hydro, or as auxiliary sources in combination with hydro
- **Management Capability;** as discussed under Capability and Demand Survey
- **Hydro Potential;** this contains a hydrograph that shows irrigation and other non-hydro water demand. Both hydrograph and FDC should have axes marked to show the conversion of flow to hydropower.
- **Hydro Design;** this is sub-divided into civil works components, penstock, hydromechanic component, hydromechanic equipment (gates and valves), turbine and generator, and transmission and distribution of power
- **Plant Factor;** involves balancing supply and demand. It comments on the availability of power when needed

FEASIBILITY STUDIES . .

- **Integrated Water Use;** this analyzes how management of the hydro project can be integrated with the management of irrigation, industrial and domestic uses of available water supply
- **Management Matters;** this basically comments on how O + M procedures and integrated water use procedures above are going to be implemented, the requirements and costs involved
- **Schedule of Operations;** a time chart starting with planning and design approval stages, through to commissioning
- **Cost Analysis;** a one page summary of project cost
- **Revenue;** statement of the various possible ways by which project will generate revenue
- **Proposed Tariff Structure**
- **Financial Analysis;** a report that demonstrates the economic viability of scheme
- **Sources of Finance;** a statement of the recommended bases for financing the scheme
- **Socio-Economic Viability**; draw together conclusions already made above on financial viability, management capability, O + M arrangements, and comments on factors which may threaten sustainability
- **Monitoring and Contingency Plans**.

SYSTEM DESIGN AND EQUIPMENT SELECTION

- Design aspects
  - Technical
  - Social-economic
  - Environmental
- Equipment selection
  - Types of turbines and characteristics
  - Control systems
  - Evacuation models

EQUIPMENT SELECTION

Basic Data Requirement

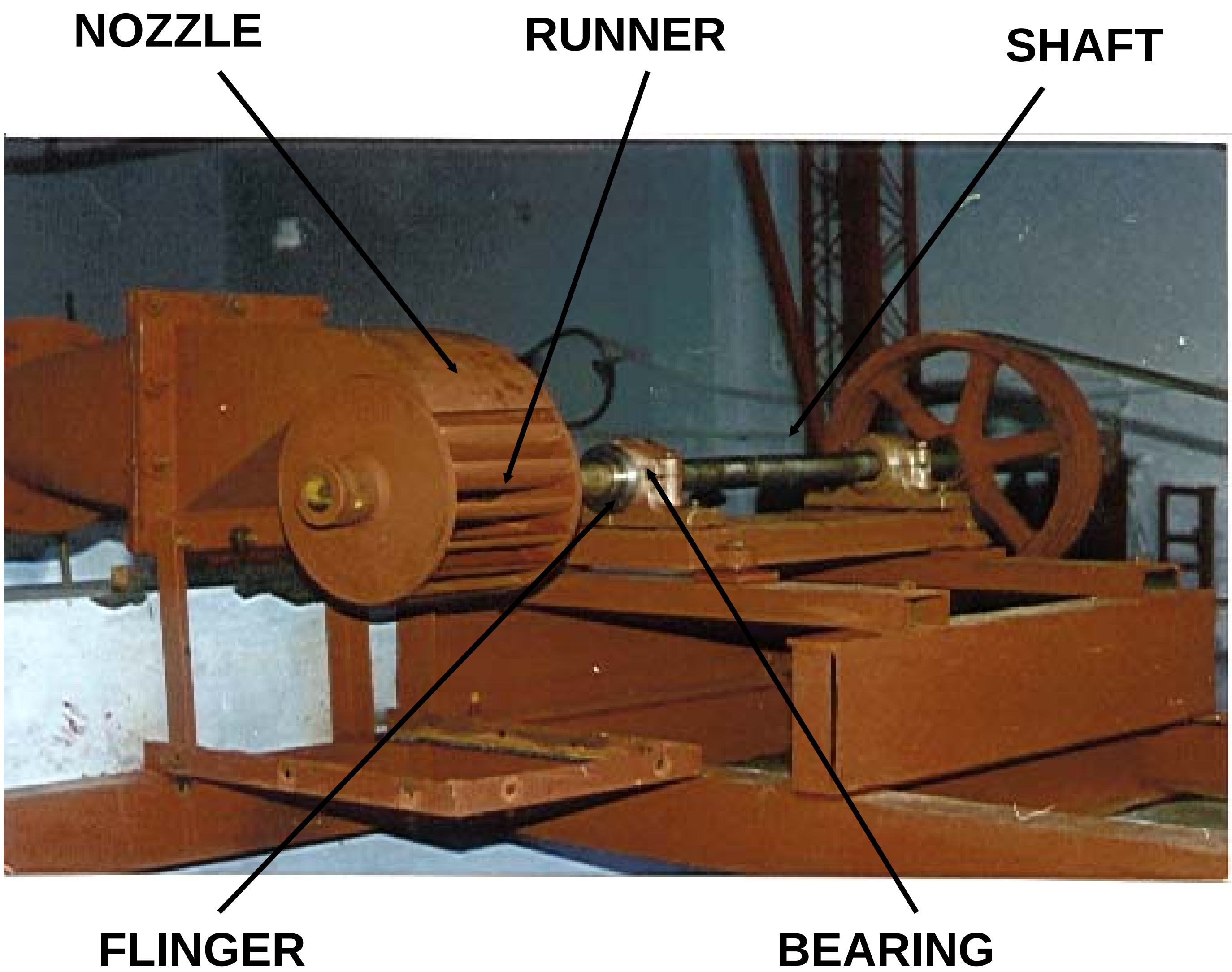
- Regulation of the reservoir and annual run-off
- Layout plan, purpose and type of the power station related hydrological, geological and topographical data.
- Stage discharge regulation curve.
- Data of water temperature, aquatics water quality and sedimentation of the river on which the power station is to be built.
- Load features of the power station
- Annual head curve
- Typical daily head curve
- Function and position of the power station in the power system.
- Charts of turbine type, application curve and application range of turbine series.

CLASSIFICATION OF TURBINES

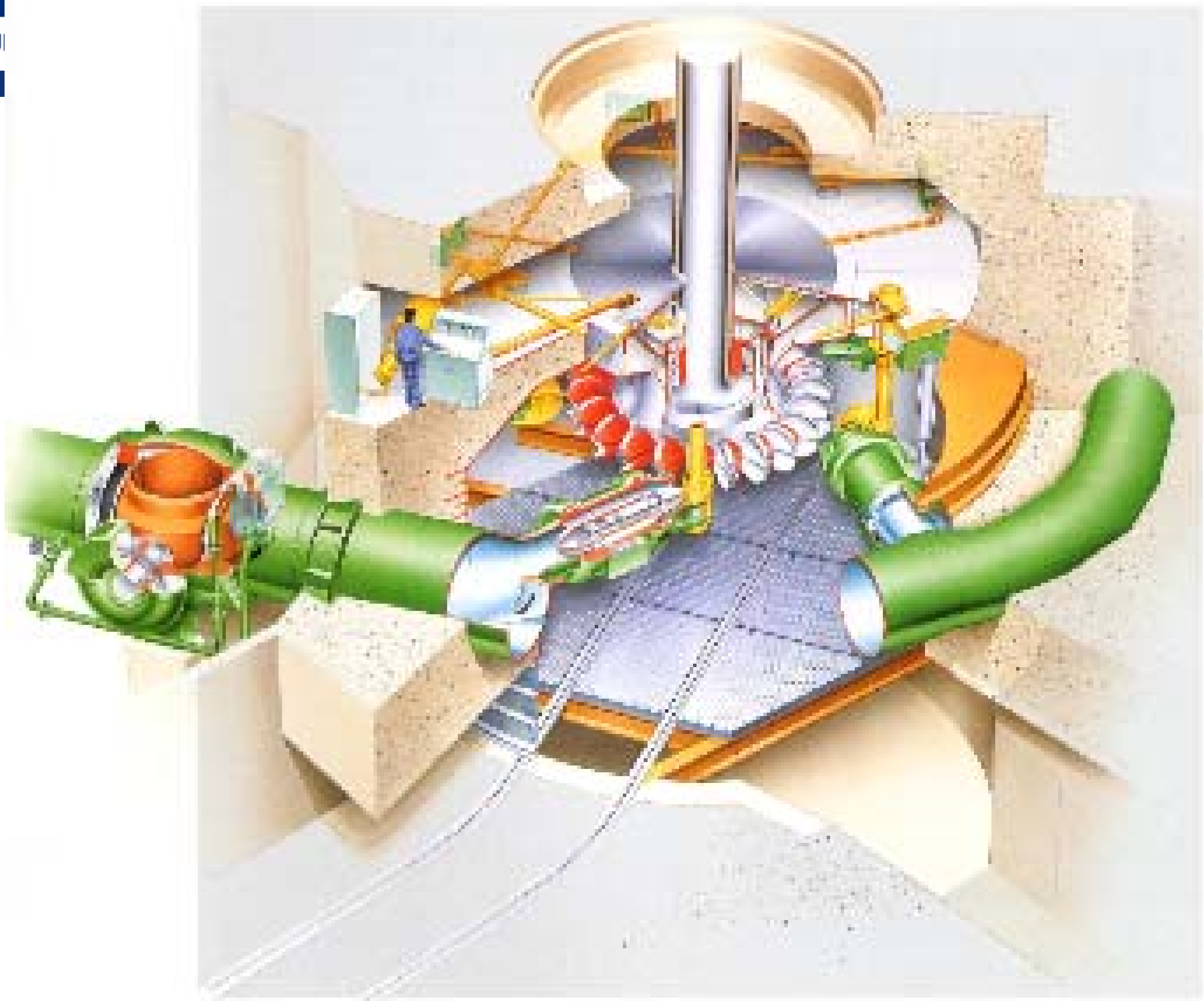
Head pressure			
Turbine Runner	**High**	**Medium**	**Low**
Impulse	Pelton Turgo Multi-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crossflow
Reaction	Francis Pump-as-turbine (PAT)	Propeller Kaplan	

Sizing of turbine depend on the flow characteristics of river or stream to be used

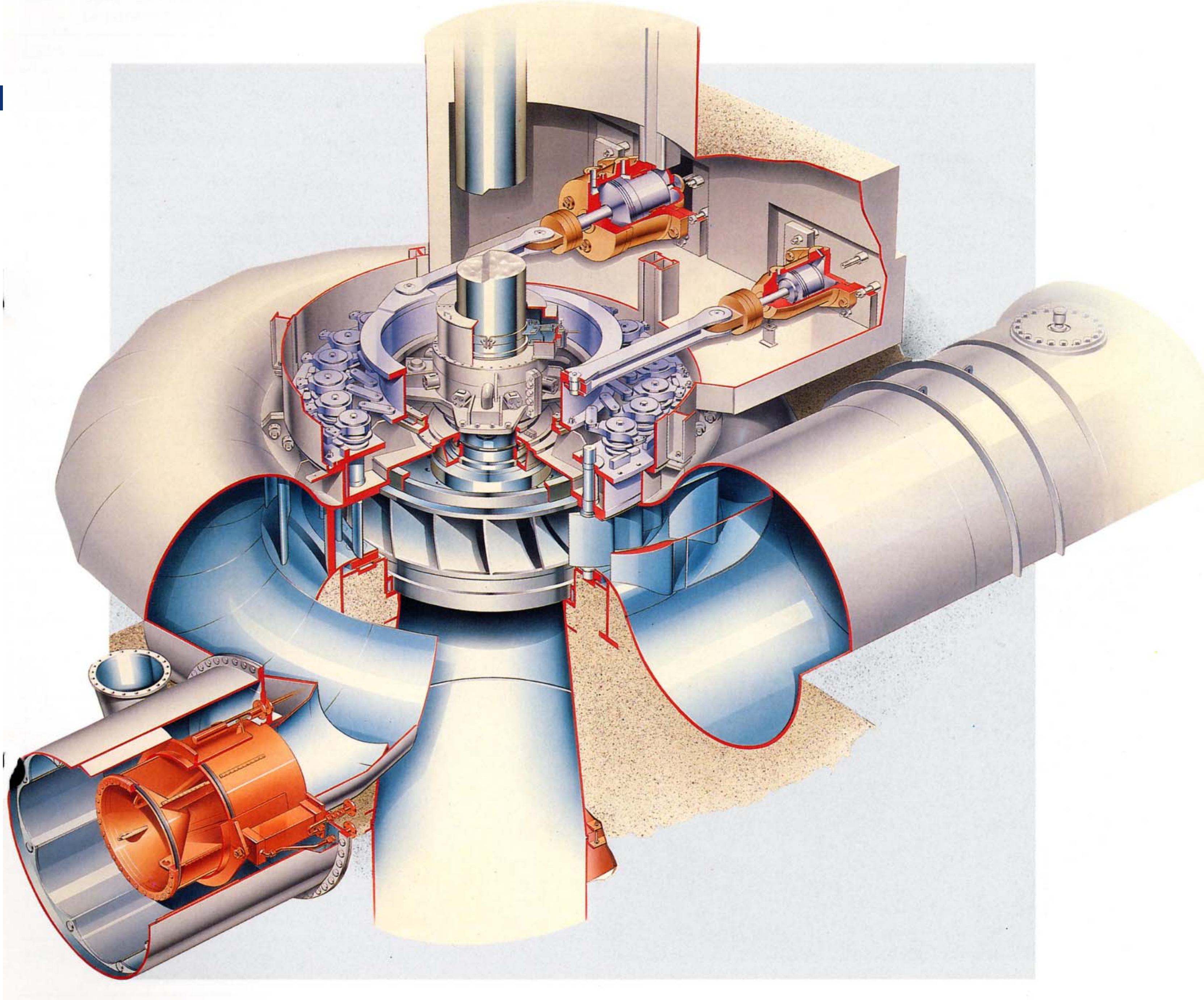
Types of Turbine	Suitable for		Remarks
	Head in m	Flow in cumec	
Water Wheel			Simple technology low efficiency, suitable for low head and small flow locally manufactured
Cross flow	1-200	0.3-9	
Turgo	40-300	1-8	
Pelton	45-1000	0.06-3	
Francis	8-200	0.3-6	Relatively poor part load efficiency. Economical above about 60 kW rating
Kaplan (Vertical)	1.1-70	3-70	Generally uneconomical for heads below 4 meters high runway speed
Axial flow			
(a) Straflow	2-50	3-20	
(b) S-Type	2-20	3.5-30	
(c) Bulb	1.25-25	3-70	



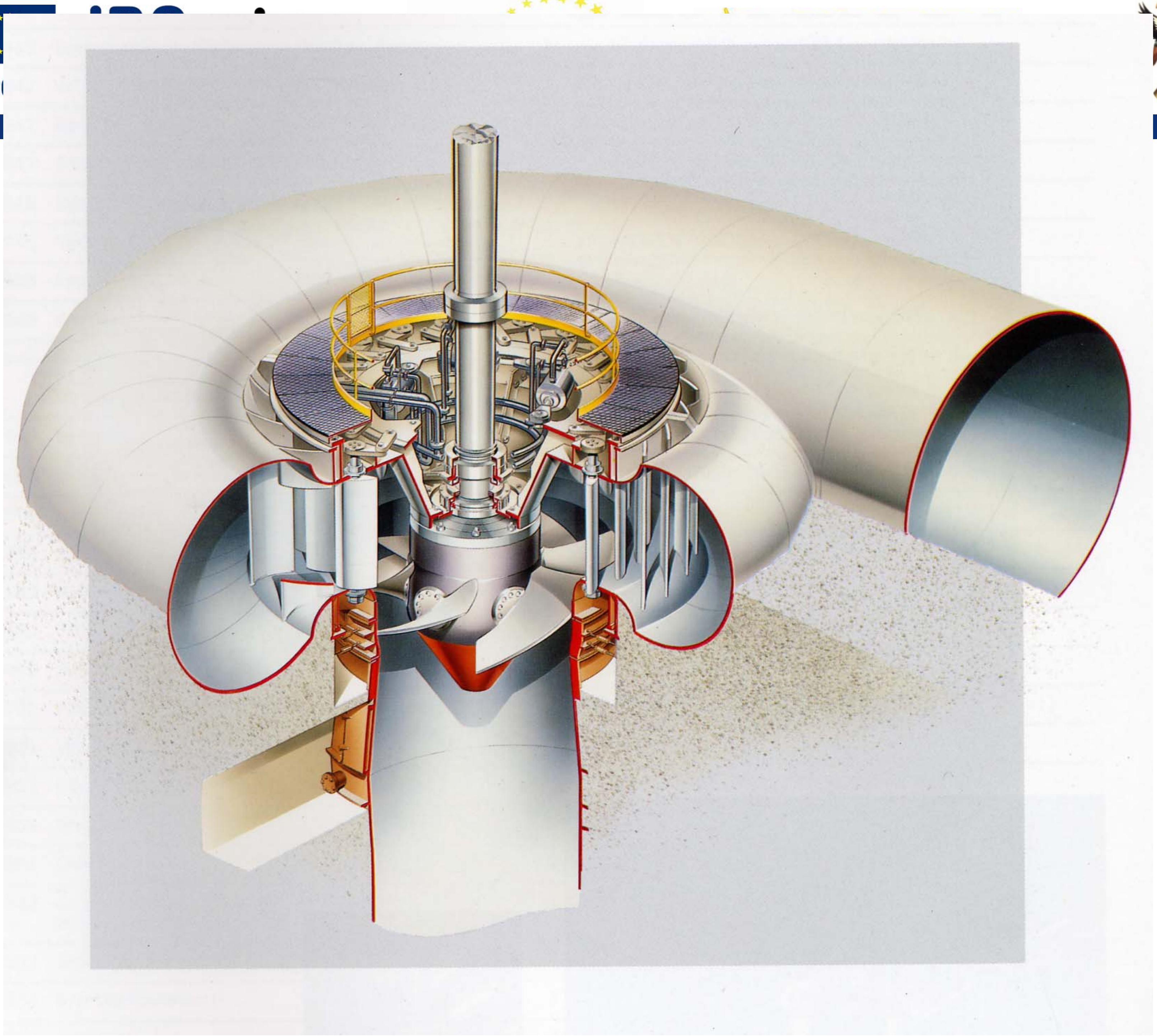
Cross flow turbine



Pelton turbine



Francis turbine



Kaplan turbine

PUMP AS TURBINE

TURBINE SELECTION

Factors governing turbine selection

A. **Head and discharge**
B. **Specific speed**
C. **Variation of head**
D. **Maximum efficiency**
E. **Part load efficiency**
F. **Initial cost of civil works**
G. **No. of units**
H. **Running and maintenance cost**
I. **Cavitation characteristics**
J. **Transporting limitations**

GENERATOR SELECTION

Generator

- The hydro-turbine generator has lower speed, larger inertia and higher strength than a steam turbine generator so as to with stand higher runaway speeds.
- In selecting generators, the main parameters to be considered are:
  - Capacity
  - Voltage
  - Speed
  - Excitation mode
  - Main shaft arrangement and bearings
  - Enclosure / casing.

MINI/MICRO HYDRO SCHEME SUSTAINABILITY

SUSTAINABILITY ASPECTS

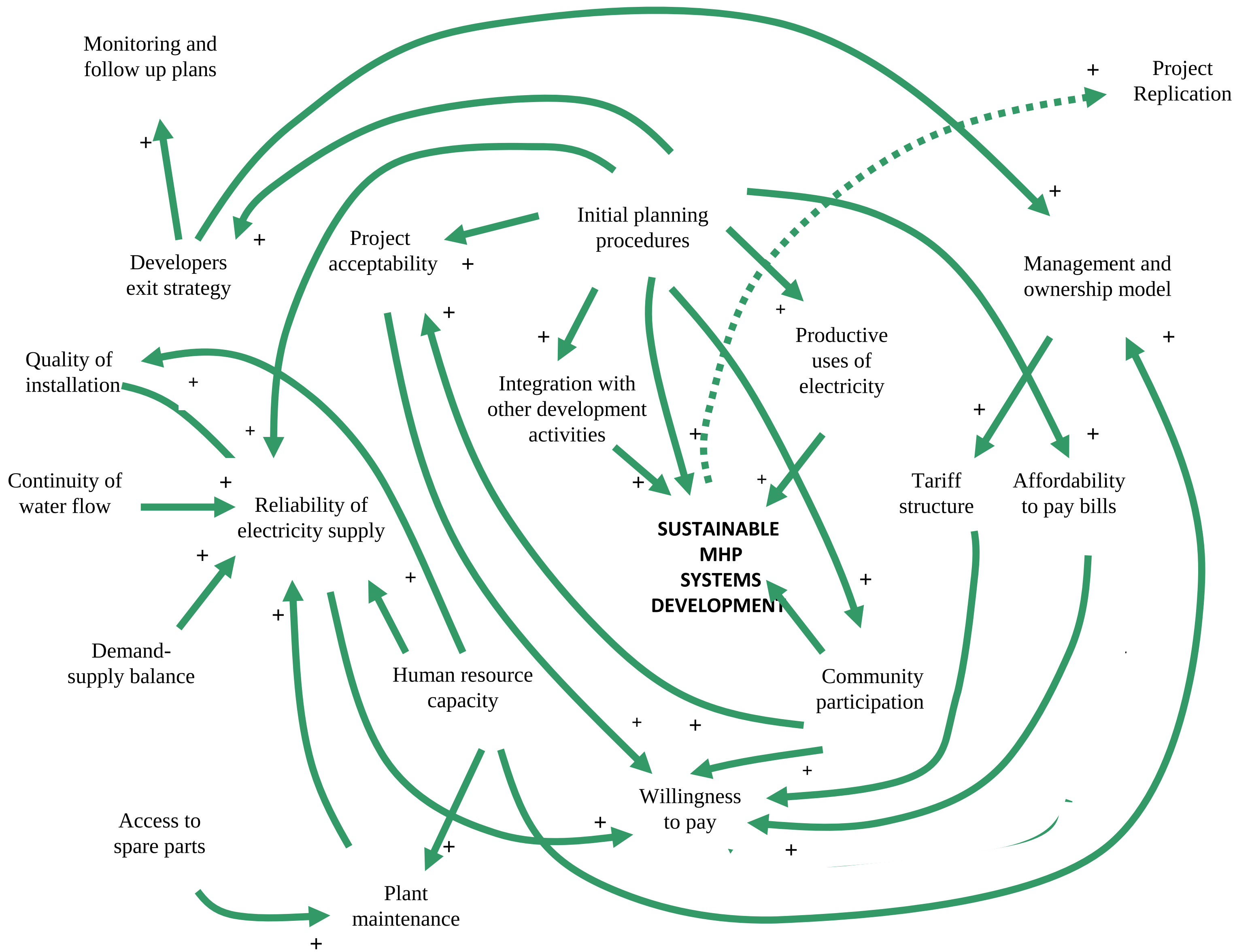
- Site selection
  - Technical – available resources, accessibility, skills
  - Social – cultural issues, social acceptability
- Community mobilisation
  - Community involvement in project appraisal
  - Community participation in project implementation
- Local authority involvement
- Management and ownership style
  - Community Cooperatives
  - Sole Entrepreneurial
  - Utility

SUSTAINABILITY ASPECTS . .

- Use of the generated power
  - – Commercial/productive versus domestic
  - – Financial analysis
    - PBP – time at which the project investment is returned (break even). The length of time required to recover the cost of an investment.
    - NPV - the value of all future cash flows, discounted at the discount rate, in today's currency.

SUSTAINABILITY ASPECTS . . . .

  - IRR – The discount rate often used in capital budgeting that makes the net present value of all cash flows from a particular project equal to zero. Generally speaking, the higher a project's internal rate of return, the more desirable it is to undertake the project. Also referred to as ROI
  - BCR - A ratio attempting to identify the relationship between the cost and benefits of a proposed project (qualitative and quantitative)
- Availability of support policy and regulatory environment
- Technology and site matching
  - Technology used
  - Available skills for maintenance



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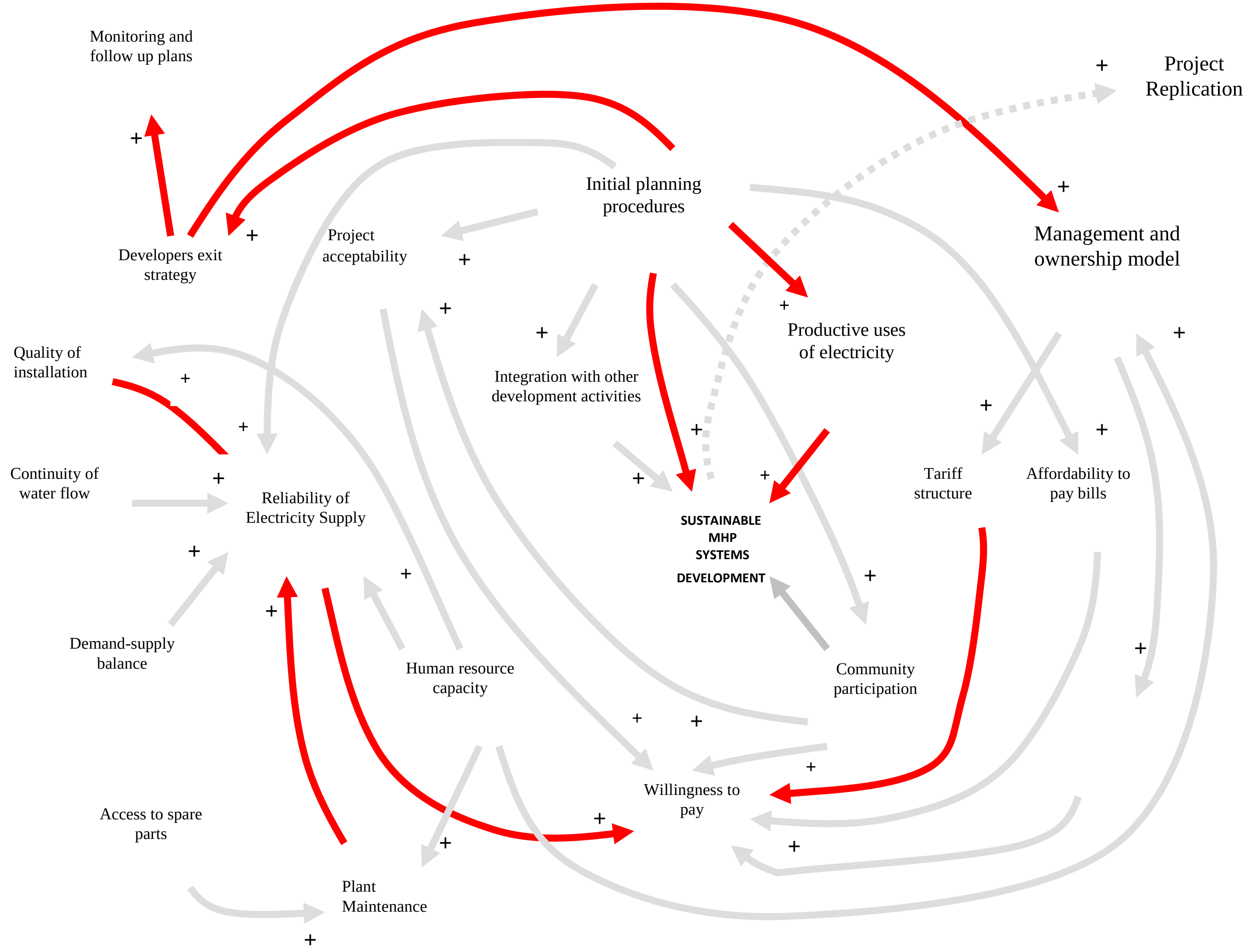
JRC EUROPEAN COMMISSION

Institute for Energy and Transport

euei EUROPEAN UNION ENERGY INITIATIVE for poverty eradication and sustainable development

CREEC



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POLICY AND REGULATORY ISSUES

POLICY AND REGULATORY ISSUES

- Government incentives (size, location, ownership)
  - Policy statements backed up with enforceable regulations
  - Energy regulatory authorities
  - Renewable Energy promotion agencies, etc
- Regulation guiding development of projects
  - Water rights/permits
  - EIA clearance
  - Power generation and use
  - Land use permits, etc

FORMS OF GOVERNMENT SUPPORT

- **Simplifying the licensing procedures by possibly creating a single window,**
- **Simplifying procedures when refurbishing abandoned sites,**
- **Creating a stable regulatory framework to reduce uncertainty,**
- **Implementing a price system that takes into account the positive externalities of this energy source compared to fossil fuels.**
- **Investment subsidies**
- **Soft loans**
- **Energy Taxes**
- **Tax credits**
- **High feed in tariffs**
- **Supported price (green tariffs, green portfolios, tenders for specific electricity sources).**

FINANCING ISSUES

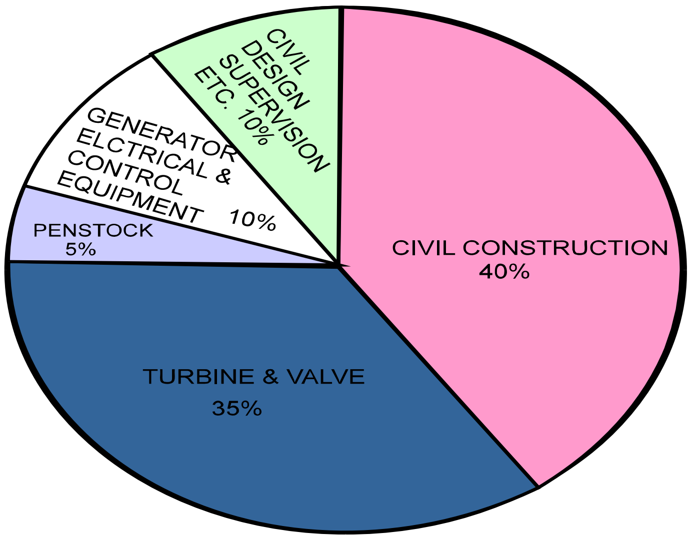
ESTIMATED PROJECT COSTS

Sl. No.	Item	Low Head	High Head
1.	Capital Cost for SHP	1200 to 1500 $ pr kW	1200 to 1500 $ Per KW
2.	Electricity Generation Depending upon water availability	4000-6000 kWh/year/kW	3500-5000 kWh/year/kW
	Annual Cost of Generation		
a	Interest	8 %	10 %
b	O&M	4 %	4%
c	Depreciation	3 %	3%
d	Insurance	1%	1%
	Total	16 %	16%
	Cost of Generation at 60% plf	3-4 cents $ per kWh	6-8 cents $ per kWh

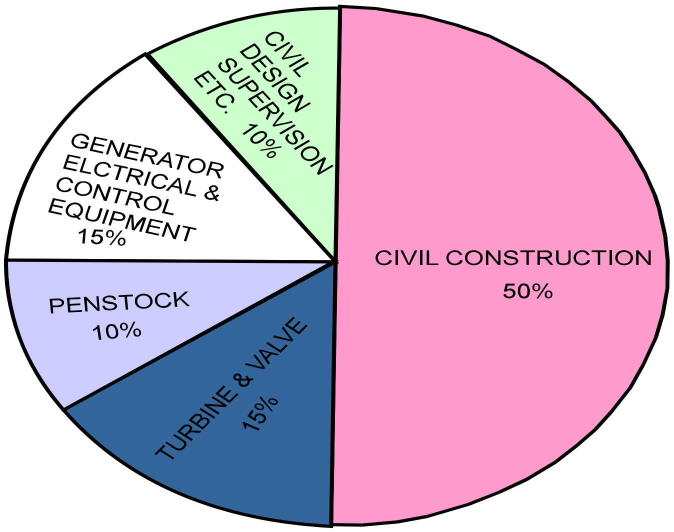
TYPICAL SHP PLANT COSTS

Cost category	Percentage of total
Civil work design, supervision, etc	10%
Electromechanical equipment (Generator, control, other electrical accessories)	10-15%
Penstock	5-10%
Civil structures	40-60%
Turbine and valves	5-35%

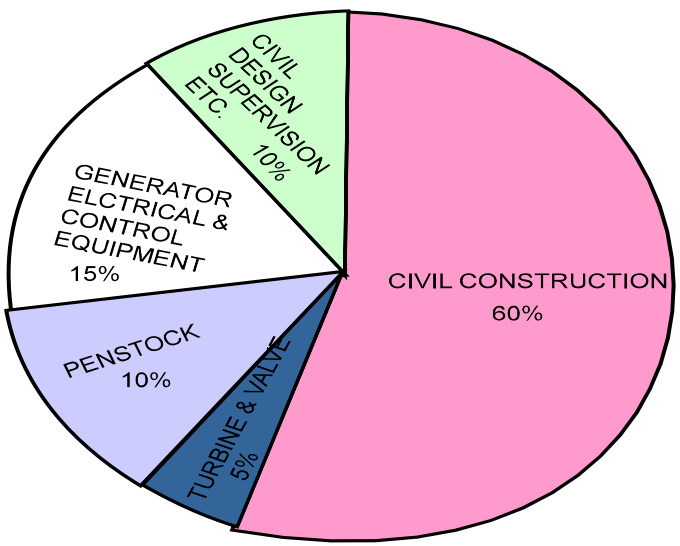
TYPICAL PLANT COST



LOW HEAD POWER STATION OR
PLANT WITH EXISTING STRUCTURES



MEDIUM HEAD POWER STATION



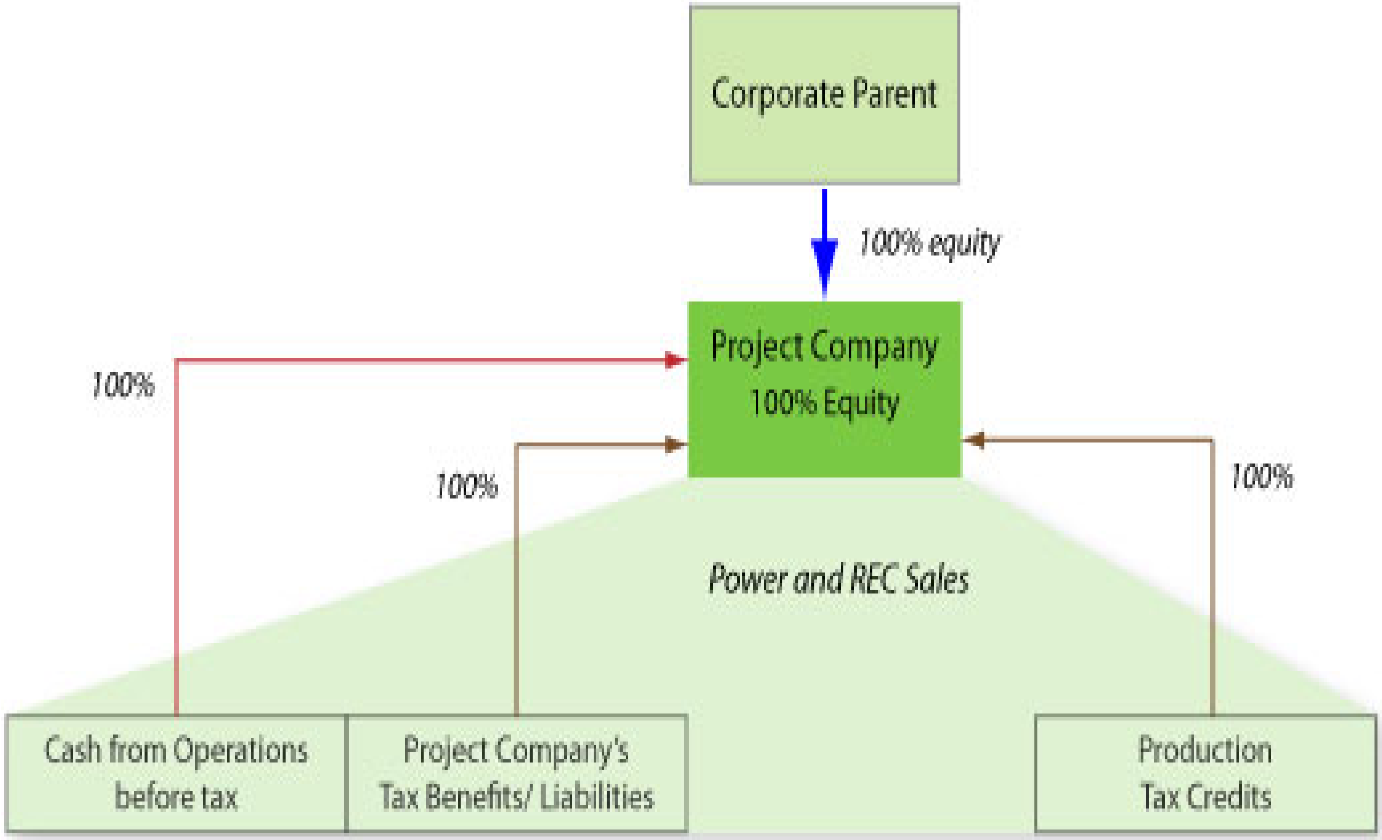
HIGH HEAD POWER STATION

FINANCING STRUCTURES

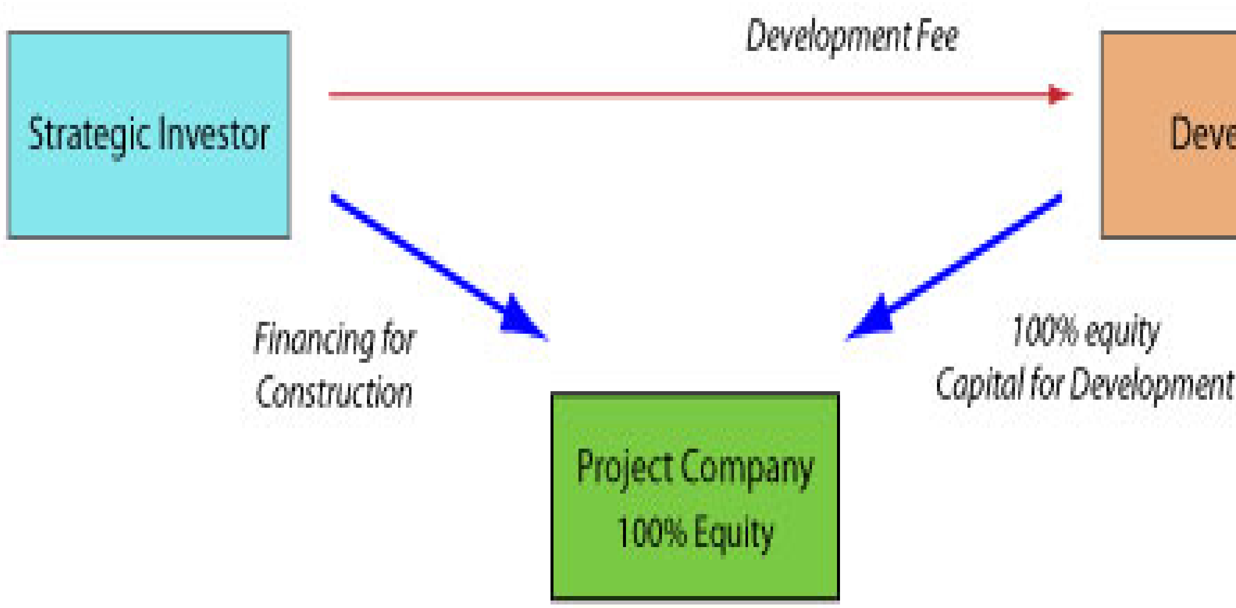
Many financing structures available, depending on the prevailing situation, some are:

- **Corporate Financing**
- **Sale before Construction**
- **Sale after Construction**
- **Investor Ownership Flip**
- **Leveraged Ownership Flip and Pay-As-You-Go ("PAYGO")**
- **Back Leveraged Structure**
- **Leveraged Lease**
- **Homeowner Model**
- **Green financing – carbon credits**

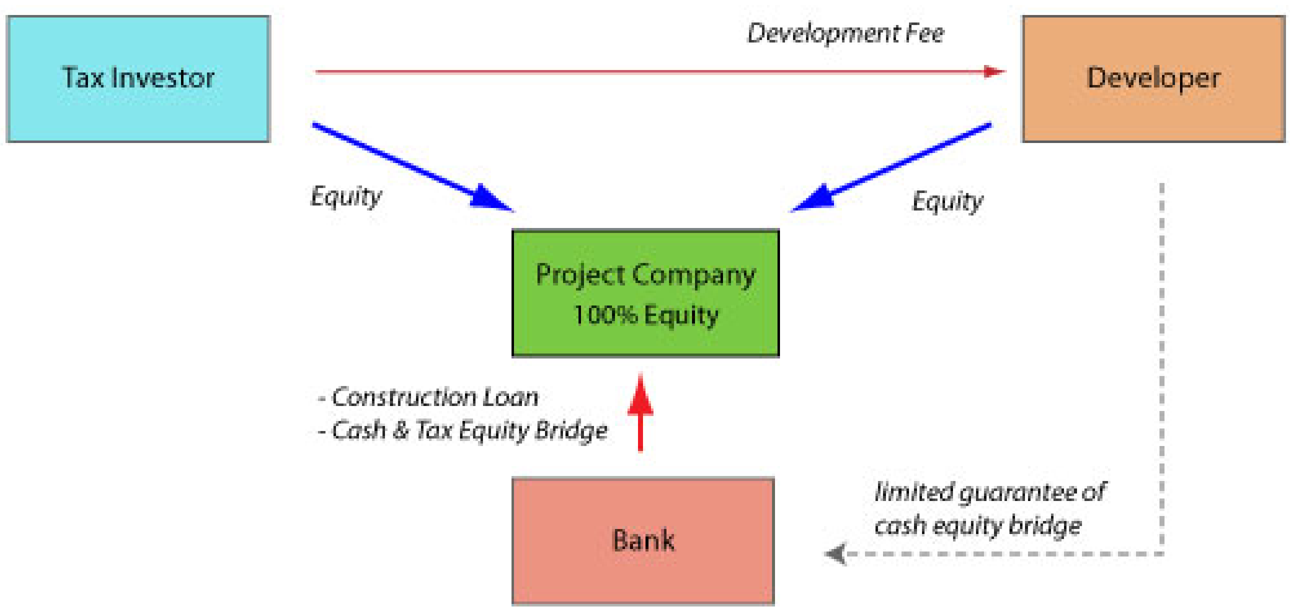
- Cooperate financing



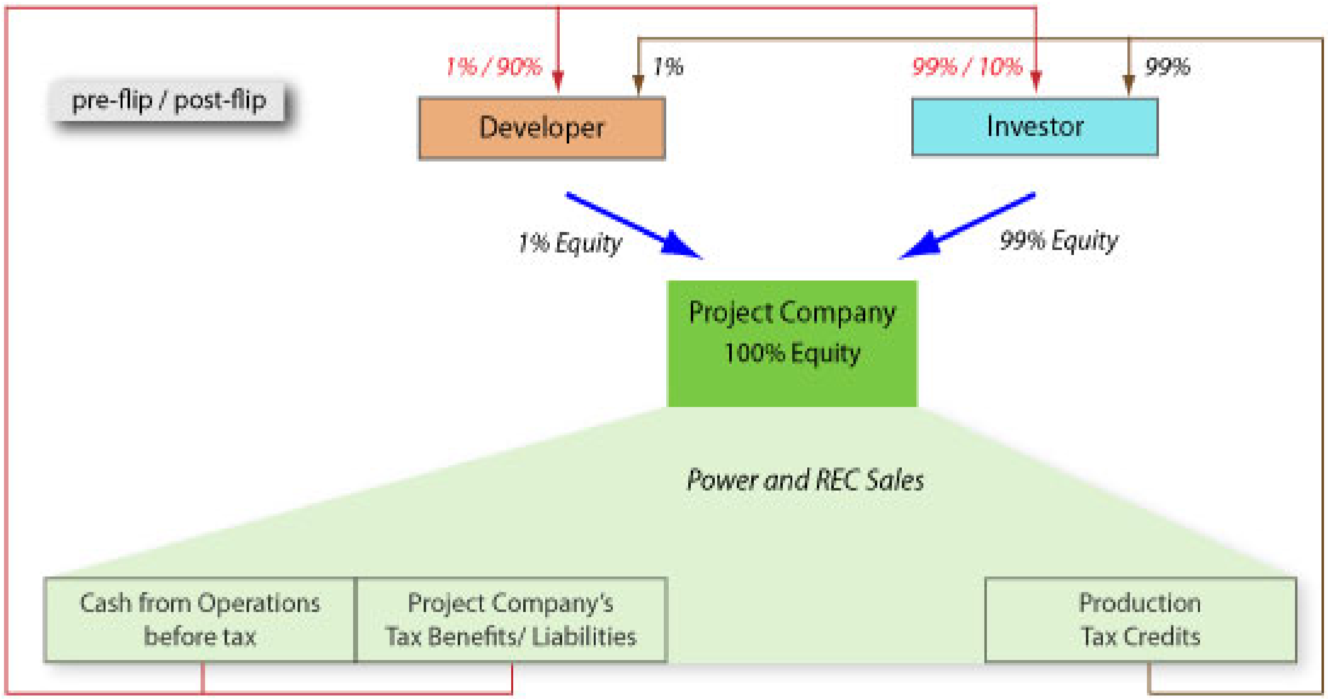
- Sale before construction



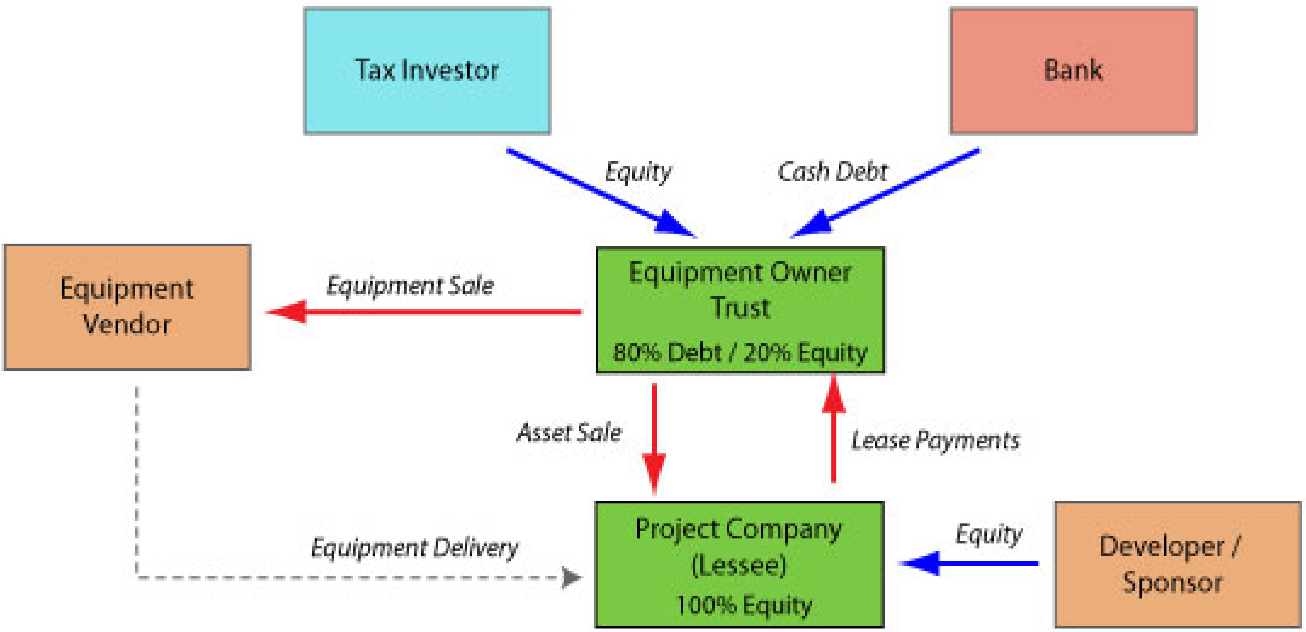
- Sale after construction



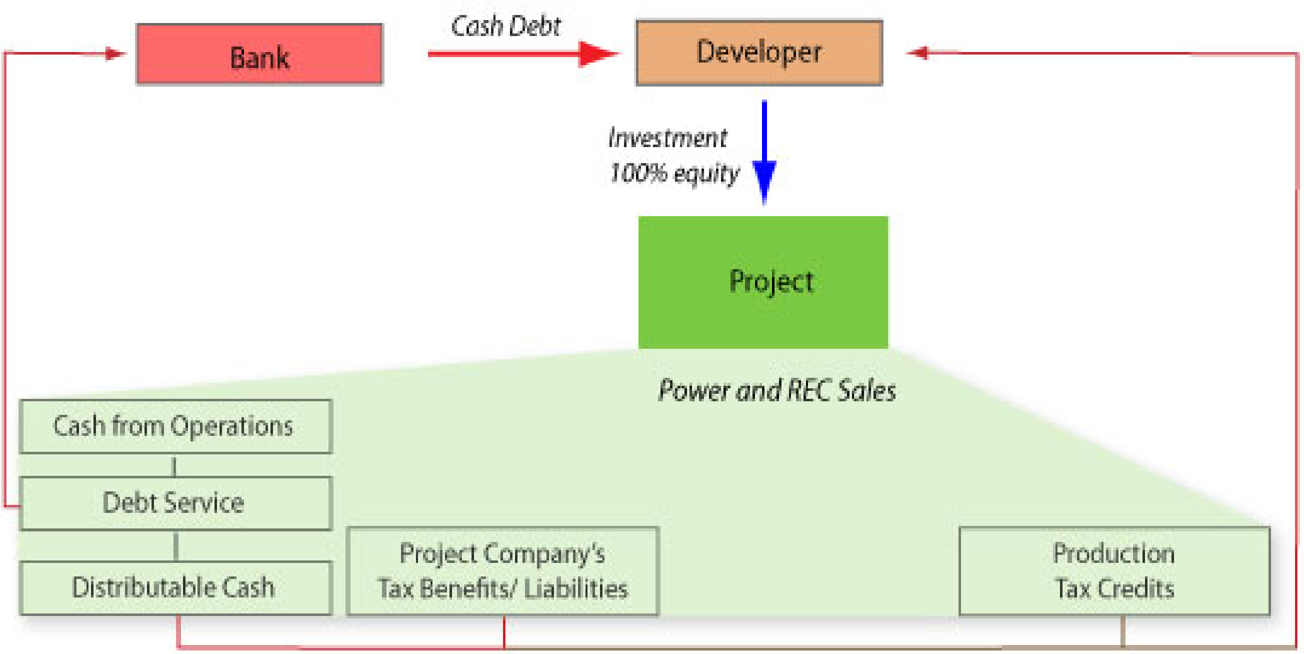
- Investor ownership flip



- Leverage lease



- Home owner model



- Green financing – carbon credits

  - Regulated Market
    - Kyoto CDM
      - Agreements between industrialised country (Annex I) and developing country (Non-Annex I)
      - Follows strict procedures as per the Kyoto agreement
      - Often good price for the CERs

  - Unregulated market
    - Voluntary agreements
    - Follows relatively simple procedures
    - Often low prices for the CERs

HYDROPOWER AND CDM

HYDROPOWER IS EFFECTIVE FOR CDM

- Hydropower is one of few carbon-free energy sources capable of large scale & low cost generation
  → large potential of GHG reduction
- If all of the "technically exploitable capability" is exploited, CO_2 reduction will be …

technically exploitable capability 11,570 TWh

× emission factor 0.5 t-CO_2/MWh

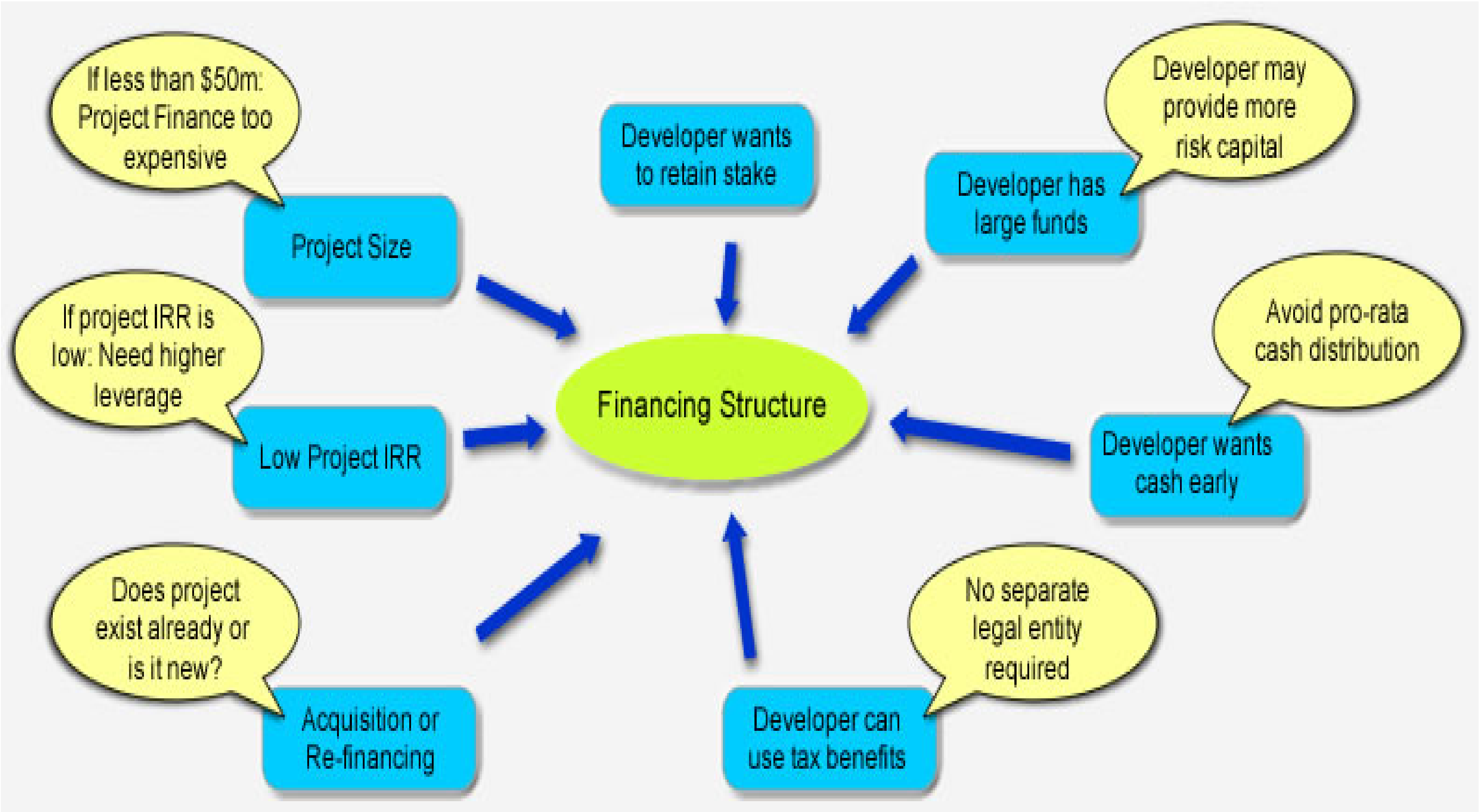
= 5.79 billion t-CO_2 (25 % of world's CO_2 emission)

HYDROPOWER AND CDM . .

CDM IS EFFECTIVE FOR HYDROPOWER

- Construction cost: 2,500 $/kW, operation rate 50%, payout period 50 years
  ⇒ electricity price: 3.1 cents/kWh (IRR 5%)
  5.8 cents/kWh (IRR 10%)
- If CO_2 reduction unit is 0.5kg-CO_2/kWh and carbon credit is \$5/t-CO_2 , additional income will be 0.25 cent/kWh
  - CO_2 reduction effect： 4 ~ 8 % of electricity price
- Carbon finance may become important for hydro-power development

- Which financing structure?



FINANCING INSTRUMENTS

- Equity
- Debt
- Guarantee
- Relief/incentives

Equity		
Sub Category	**Function**	**Source**
Ordinary Shares	Risk capital from developer or sponsor	Sponsor
Preference Shares	Senior to ordinary shares, typically from tax investor; sometimes providing a cumulative dividend.	Institutional Investors Investment Funds Tax Investors
Guarantee		
Exchange Rate Risk	A commercial lender provides a loan to the project entity (the importing entity), at below market interest rates. The Export-Import bank provides compensation for the difference between commercial rate and below-market rate	Export Credit Agency
Political Risk	Limited protection against risks of sovereign non-performance and against certain *Force Majeure* risks.	Word Bank
Relief /Incentives		
Tax Credits **Tax Holidays** **Duty exemption**	Individual governments may offer tax incentives	Host governments
Other forms of incentives	Connection, capacity, purpose, etc	Host governments

Debt

Sub Category	Function	Source
Subordinated Loan / Mezzanine	Usually fixed rate, long-term and unsecured. May be considered as equity. Can be used to cover construction overruns or other guaranteed payments	Lenders specialising in mezzanine debt
Syndicated Loans	Loan provided by two or more lenders, governed by a single loan agreement. May have different agreements for construction and operating phase of project. Provide long-term finance	Banks
Senior Debt - unsecured / secured	Large unsecured loans are only available to creditworthy corporations. Banks tend to limit their risk to 5 - 10 years.	Commercial banks
Development Loan	Financing provided during development of project to a sponsor with insufficient resources.	▪ Lender with project experience ▪ World Bank (only if project can not secure borrowing at reasonable rates from any other sources) ▪ Vendor

Debt…

Sub Category	Function	Source
Intermediary Loan	Export-Import bank lends to a financial intermediary (commercial bank), which in turns lends to the project.	Export Credit Agency
Private Placement	Direct sale of long-term debt / equity	Sophisticated investors including insurance companies, pension funds, trading companies
Eurobond	Issued in amounts averaging $100m without prior registration or approval by any particular government. Terms usually range from 10 - 15 years. Loans may be made in any currency, fewer covenant than syndicated bank loans, and accessible through a large and liquid market. However, a credit rating for the project entity is required which could be both costly and time-consuming to obtain. Also, bond issues tend not to allow changes to the underlying project.	Capital Markets

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