WORLD BANK GROUP

A BRIEF INTRODUCTION TO SMALL HYDROPOWER

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ESMAP—SAR—EAP RENEWABLE ENERGY TRAINING PROGRAM

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OUTLINE

SN	TITLE	
1	**Introduction** ▪ Small hydro worldwide ▪ Classification, Advantages and Components	
2	**The Nuts & Bolts** ▪ Power equation ▪ Hydrology, Turbine selection, Environmental aspects	
3	**Global experiences of small hydros: lessons learnt** ▪ Contracts and Risk Management ▪ Technical considerations: headworks and sediments	
4	**Grid or Off Grid?** ▪ Case studies	
5	**Financing of small hydros** ▪ Costs and Case study of a PPP	
6	**Removing barriers** ▪ Recommendations from Alliance for Renewable Energy	
7	**Q & A**	

There is no SINGLE SPECIALIST

WET SUBJECTS	DRY SUBJECTS
Hydrology	Survey
Hydraulics	Geology
Dams	Geotechnical
Sediments	Tunneling
Water Quality	Electrical
Civil Engineering	Mechanical
	Materials
	Law
	Environment
	Social

1. INTRODUCTION

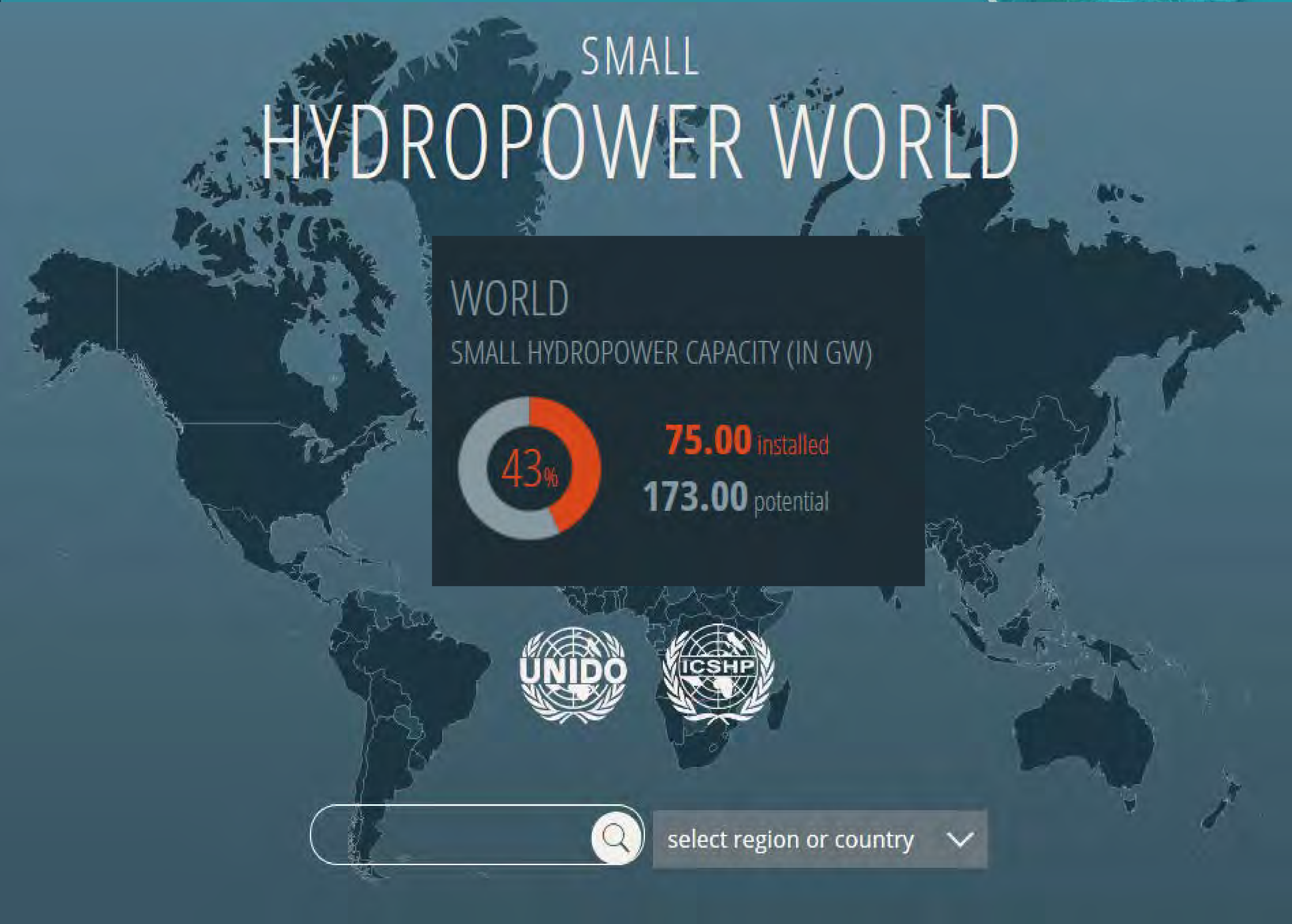
How is small hydropower doing world wide

Classification and definitions

Advantages of small hydro

Components of small hydro

www.smallhydroworld.org



CLASSIFICATION OF SMALL HYDROPOWER

COUNTRY	SMALL (MW)	MINI (MW)	MICRO (KW)
Austria	≤ 10	0.600-2	5-500
China	≤ 50	≤ 2	≤ 100
India	2-25	0.101-2	≤ 100
Indonesia	5-10	0.200-5	1-200
Pakistan	≤ 50	0.150-5	≤ 150
Thailand	6-15	0.200-6	≤ 200

Source: *UNIDO 2014*

CLASSIFICATION FOR ALL HYDROS

Classification based on different approach (not mutually exclusive).

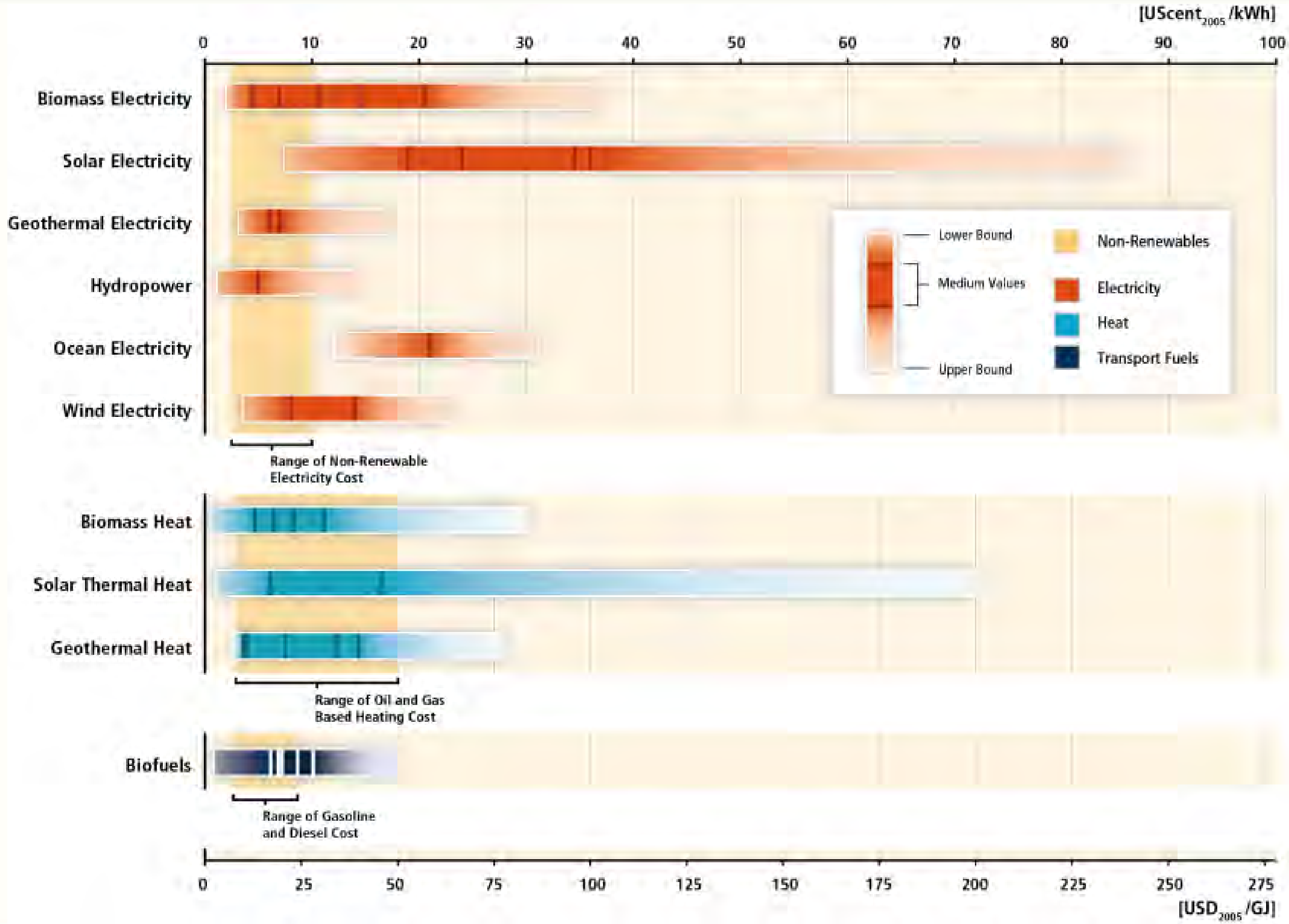
- By purpose (single or multi-purpose)
- By types (run-of-river, reservoirs)
- By size (micro, small, large)
- By head (high, medium, low or ultra low)
- By connection system (isolated/off grid or grid connected)
- By Regulation performance (Peaking Run-of-river or Seasonal regulation through storage)

ADVANTAGES OF SMALL HYDRO

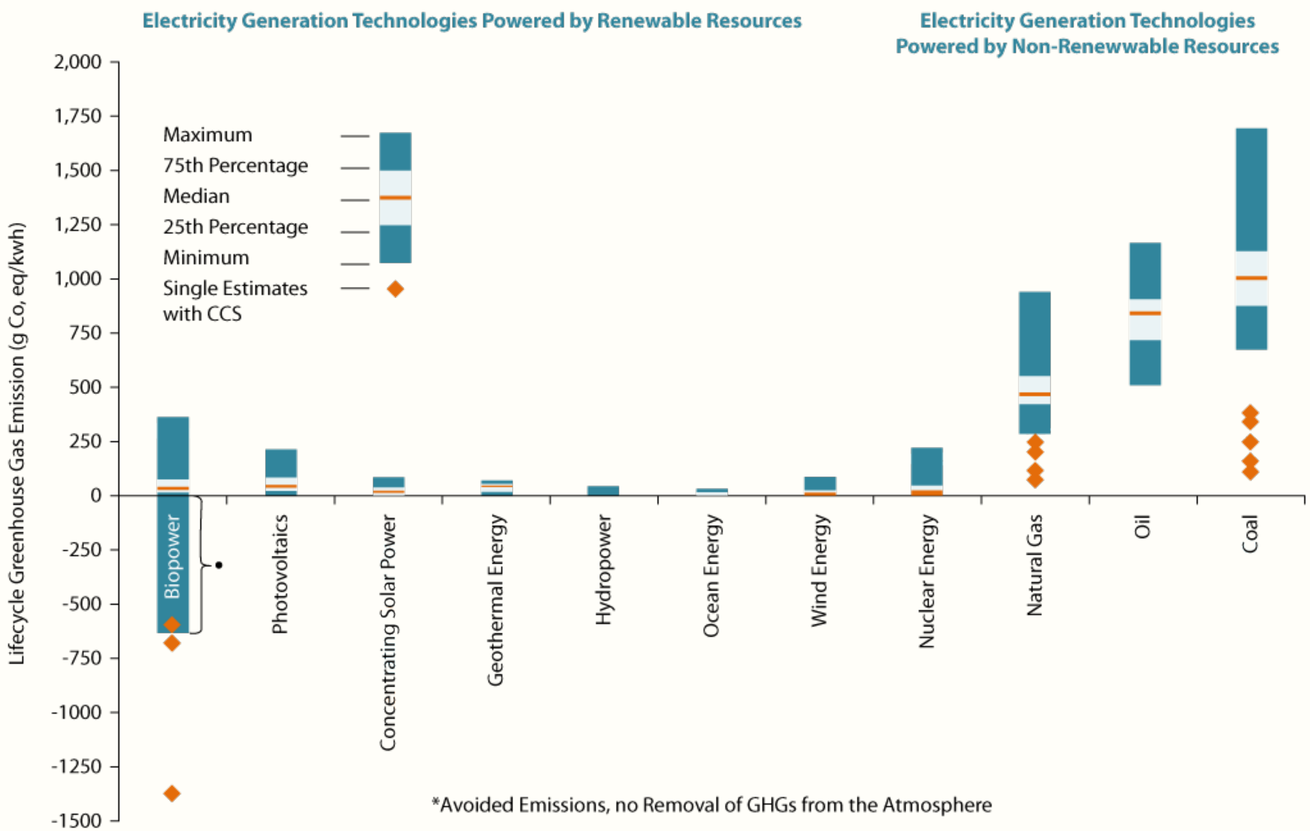
- **Green Energy**. it is green, environmentally and socially responsible energy.
- **Proven Technology**. It has been around for many years, and it is a system that has minimum technology risk. > 2000 years – water wheels
- **Life Span**. It is estimated that run of river projects can last over 50 years. Mechanical parts require refurbishment from time to time in order to maintain productivity levels.
- **Operating Costs**. Compared to other types of thermal power plants, hydropower is green power that requires no fuel. The only costs associated with operation are maintenance, repairs, and taxes, principally water and property.

Today 20% of the world's electricity is supplied by hydropower

LEVELIZED COST OF ENERGY (SOURCE IPCC, 2011)



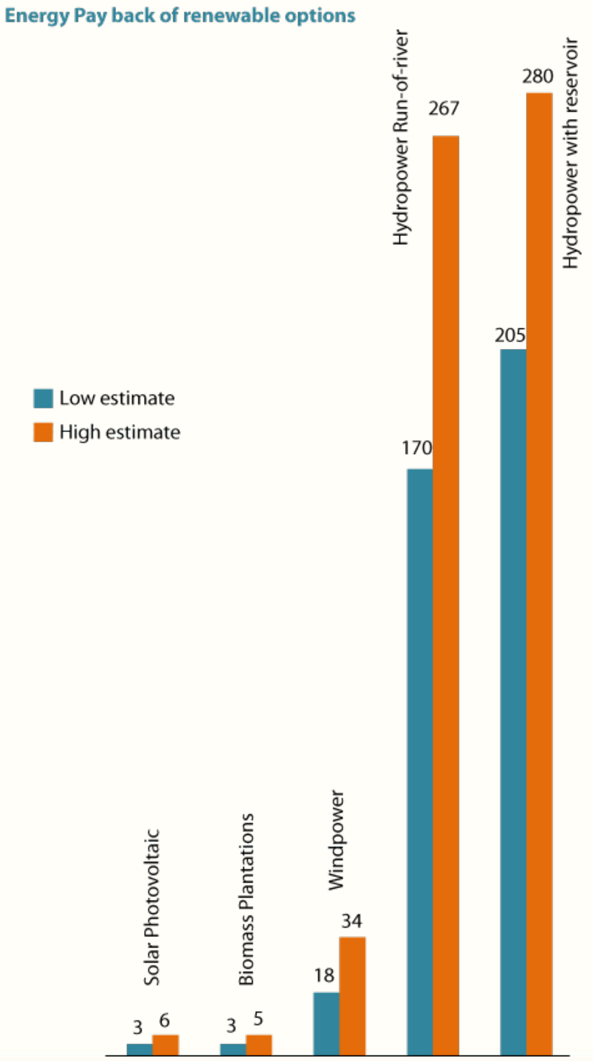
MITIGATING CLIMATE CHANGE

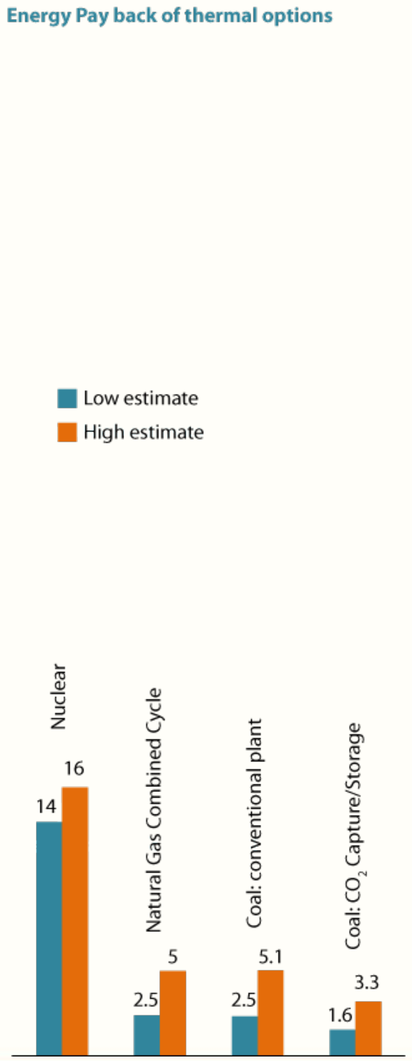


Count of Estimates	222(+4)	124	42	8	28	10	126	125	83(+7)	24	169(+12)
Count of References	52(+0)	26	13	6	11	5	49	32	36(+4)	10	50(+10)

*Majority of lifecycle GHG emission estimates for hydropower cluster between **about 4 and 14 g CO_2eq/kWh,** But under certain scenarios there is the potential for much larger quantities of GHG emissions- source: IPCC 2011 SRREN- SPM*

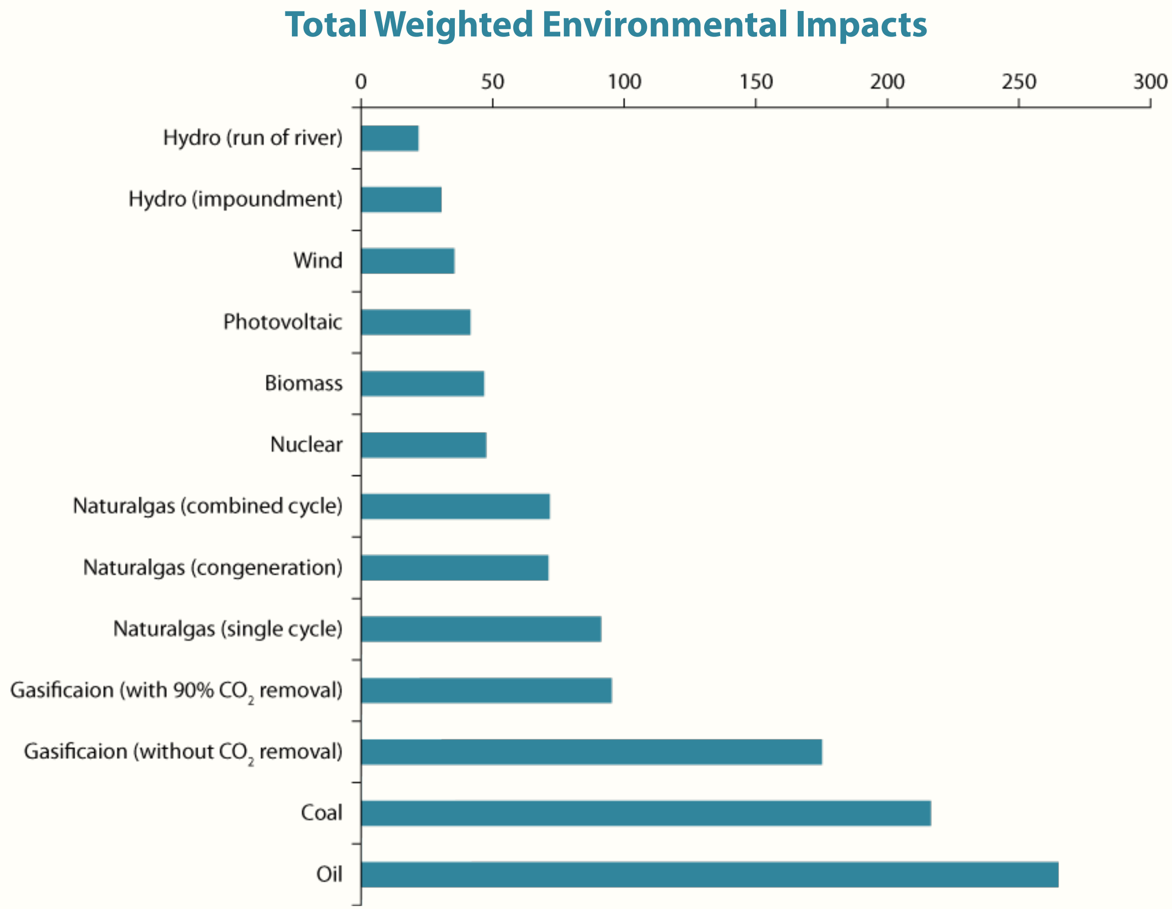
ENERGY PAY BACK RATIO





Source: *Gagnon, 2008*

COMPARISON OF SCORED ENVIRONMENTAL IMPACTS



Note: Score based on contaminant emissions, Co_2, radioactivity, land use, water and waste impacts and resource availability. The total Weighted Impact is calculated by applying a weight of 10 to contaminant emissions, 20 to greenhouse gases , and 1 to all other categories.

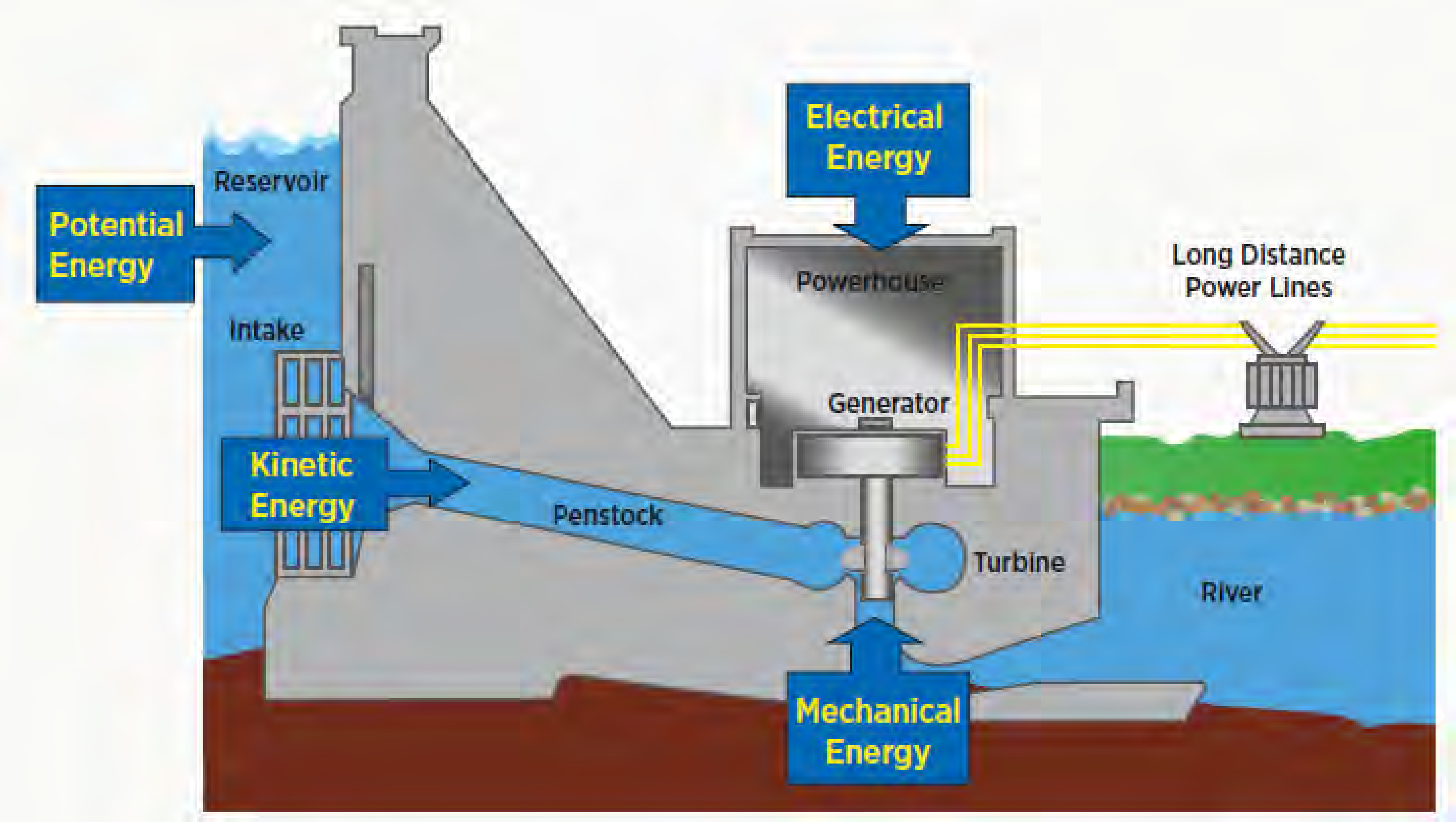
Source: Senes Consultants: Ontario Power Authority.

COMPONENTS

Source: *Soren Henrich; Watershed Watch Salmon Society*

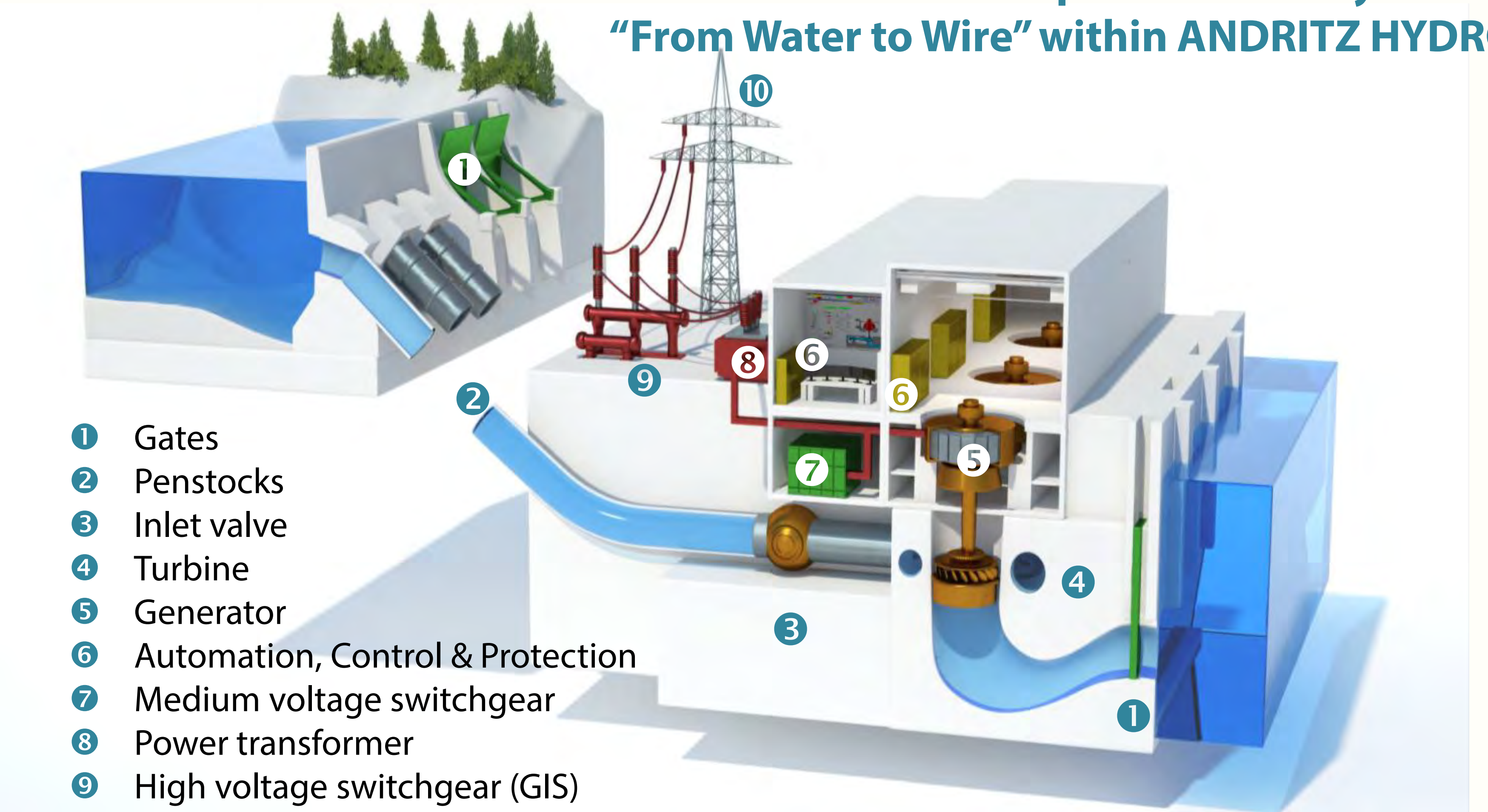
- **Headworks** – a weir/dam, a spillway and intake + settling basin (optional)
- **Water conveyance structures** – canal, penstock
- **Turbines** – use available head and flow to rotate a shaft to drive a generator
- **Generators** – convert the shaft power into electricity
- **Control, protection and switchgear** – for starting, stopping and operation
- **Powerhouse** – houses turbines, generators, control systems, switchgear etc.
- **Transformers** – convert generator voltage to a voltage suitable for transmission

ENERGY CONVERSIONS



FROM WATER TO WIRE

Extensive know-how of products and systems - "From Water to Wire" within ANDRITZ HYDRO



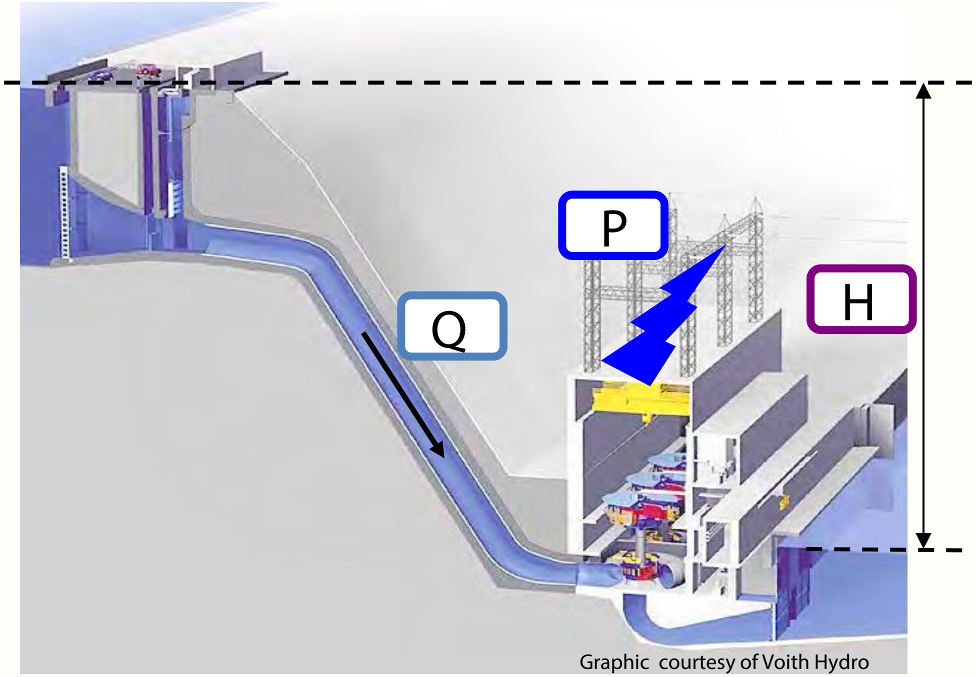
1. Gates
2. Penstocks
3. Inlet valve
4. Turbine
5. Generator
6. Automation, Control & Protection
7. Medium voltage switchgear
8. Power transformer
9. High voltage switchgear (GIS)
10. Transmission line

DIFFERENCES BETWEEN MICRO, SMALL AND LARGE

DESCRIPTION	MICRO HYDRO (<100KW)	SMALL HYDROS	LARGER HYDROS
Type	Mostly run-of-the-river	Both run-of-the-river and peaking storage	Both run-of-the-river, peaking and seasonal storage
Nature of intake	Temporary or semi-permanent	Permanent	Permanent
Tunnels and underground structures	Rare	Common	Common
River diversion	Non	Depending on size	Common
Surge shaft	Rare, forebay acts as a surge tank	Common	Common
Grid connection	Isolated (not connected to the national grid)	Mostly grid connected	Grid connected
Unlined canals	Common	Rare	Rare
Turbine type	Cross flow, Pico (less than 10 kw) Peltric sets	Pelton/Francis/Axial Flow	Kaplan/Pelton/Francis

2. THE NUTS & BOLTS

THE PHYSICS



POWER ~ HEAD x DISCHARGE

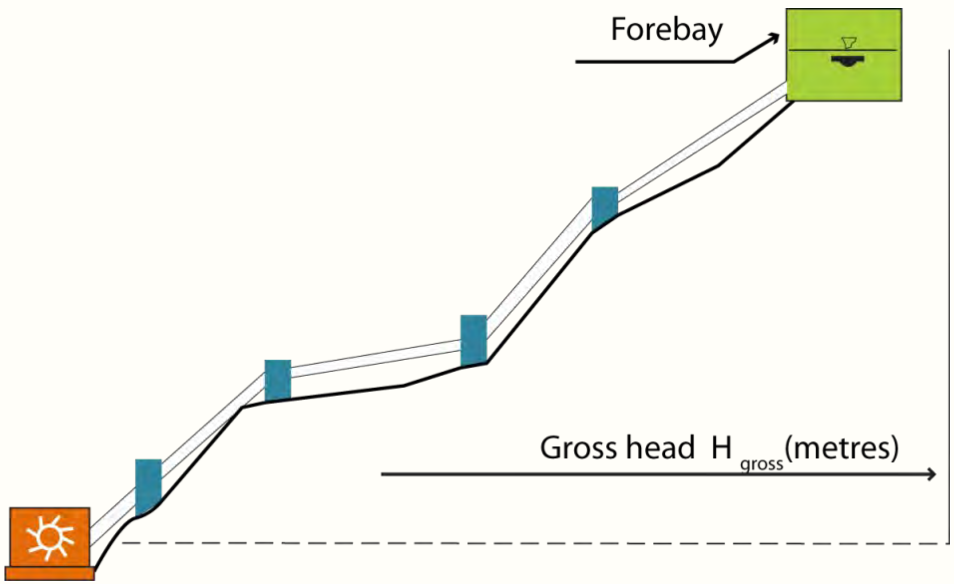
- Discharge drives size of the plant
- Head drives type of plant

Classification according to the "Head":
High head: 100-m and above
Medium head: 30-100 m
Low head: 2-30 m

$P = Q * H * 9.81 * \eta_t * \eta_g$ (kW)

where:
P=power output in kW Q=turbine flow in m^3/s H=head in meters of water 9.81=acceleration due to gravity (m/s^2)
η_t=turbine efficiency (0.87-0.92) η_g= generator efficiency (0.94-0.98)

HEAD



H_{gross} is the difference between the water level at the forebay and the turbine centerline level (or tailrace if a draft tube is used).

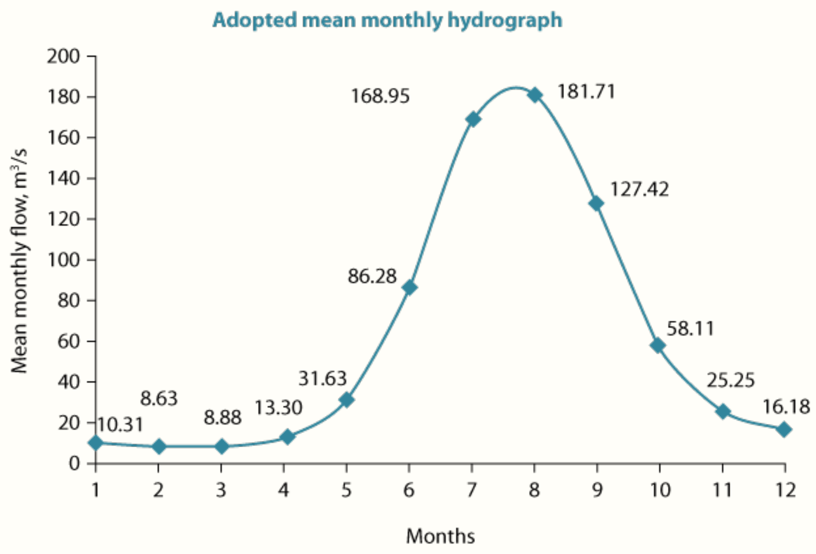
H_{net} is the pressure head at the entrance to the turbine.

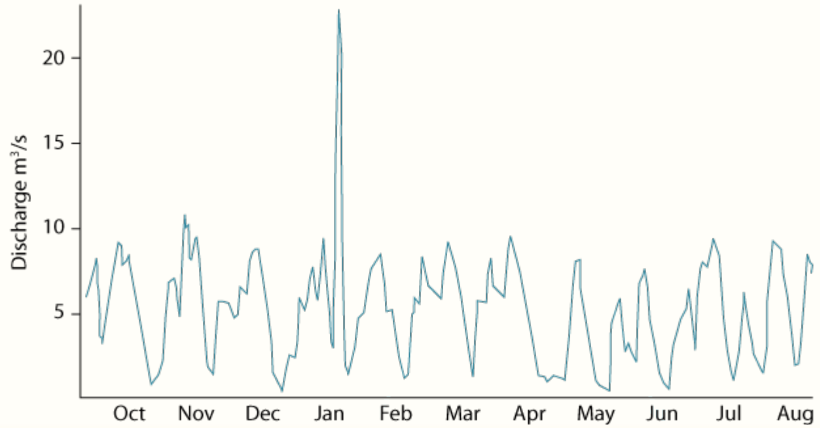
$H_{net} = H_{gross} -$ conveyance losses in the penstock

Flow Measurements

DIRECT METHOD	INDIRECT METHOD
VELOCITY- AREA METHOD	USING FLOW MEASURING DEVICES WIERS and FLUMES
DILUTION METHOD	SLOPE –AREA METHOD
ULTRASONIC METHOD	STAGE –DISCHARGE METHOD
ELECTROMAGNETIC METHOD	

HYDROGRAPH : SEASONAL VARIATIONS

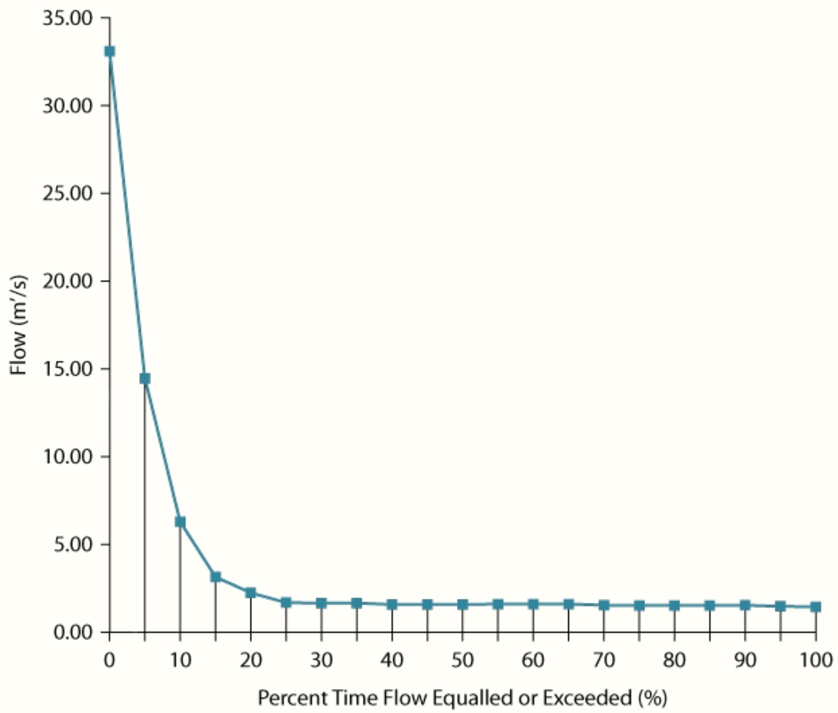




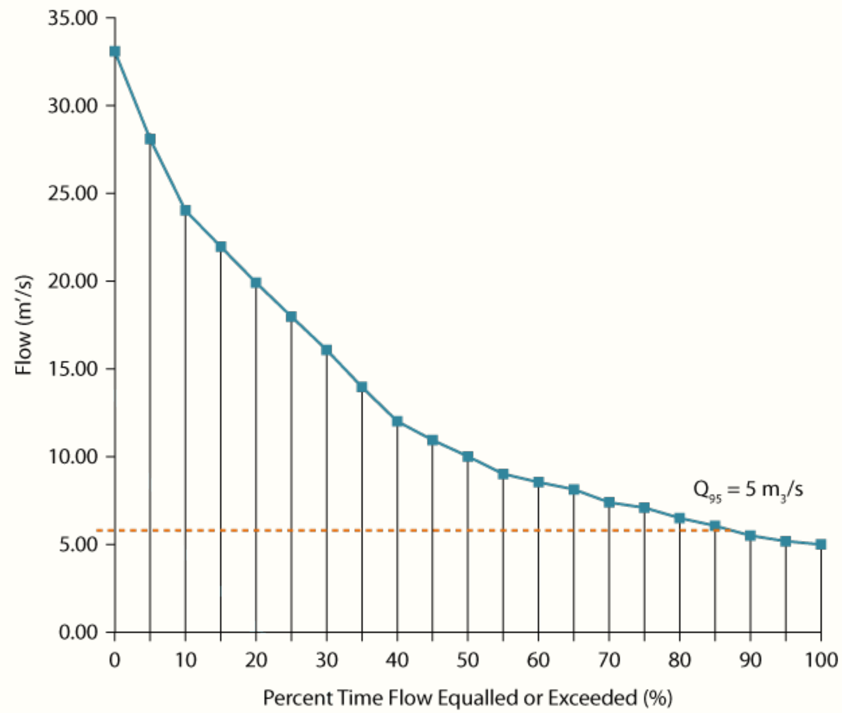
MONTH	FLOW (M^3/S)	POWER (MW)
Jan	10.31	11.1
Feb	8.63	9.3
March	8.88	9.6
April	13.30	14.4
May	31.63	34.1
June	86.28	93.1
July	168.95	182.3
Aug	181.71	196.1
Sep	127.42	137.5
Oct	58.11	62.7
Nov	25.25	27.2
Dec	16.18	17.5

FLOW DURATION CURVE

The FDC is used to assess the availability of flow and corresponding power and to decide on the "design flow" in order to select the turbine.

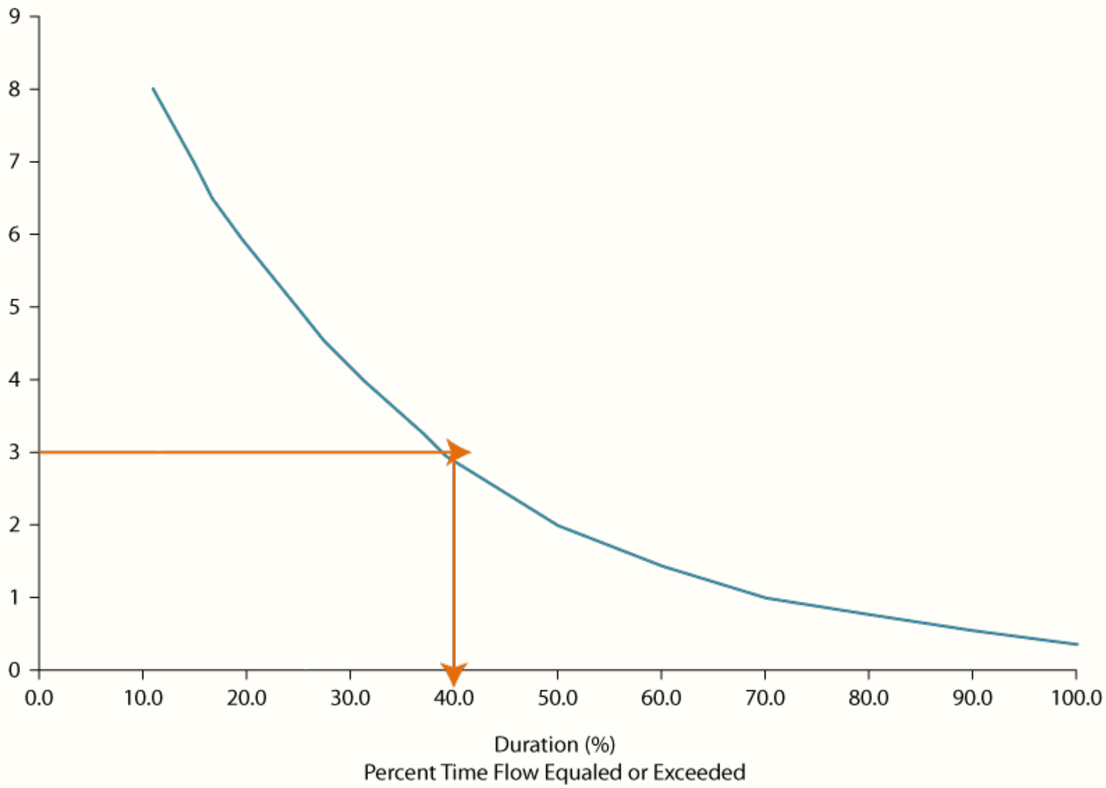


FDC for river with a high flow for a short time



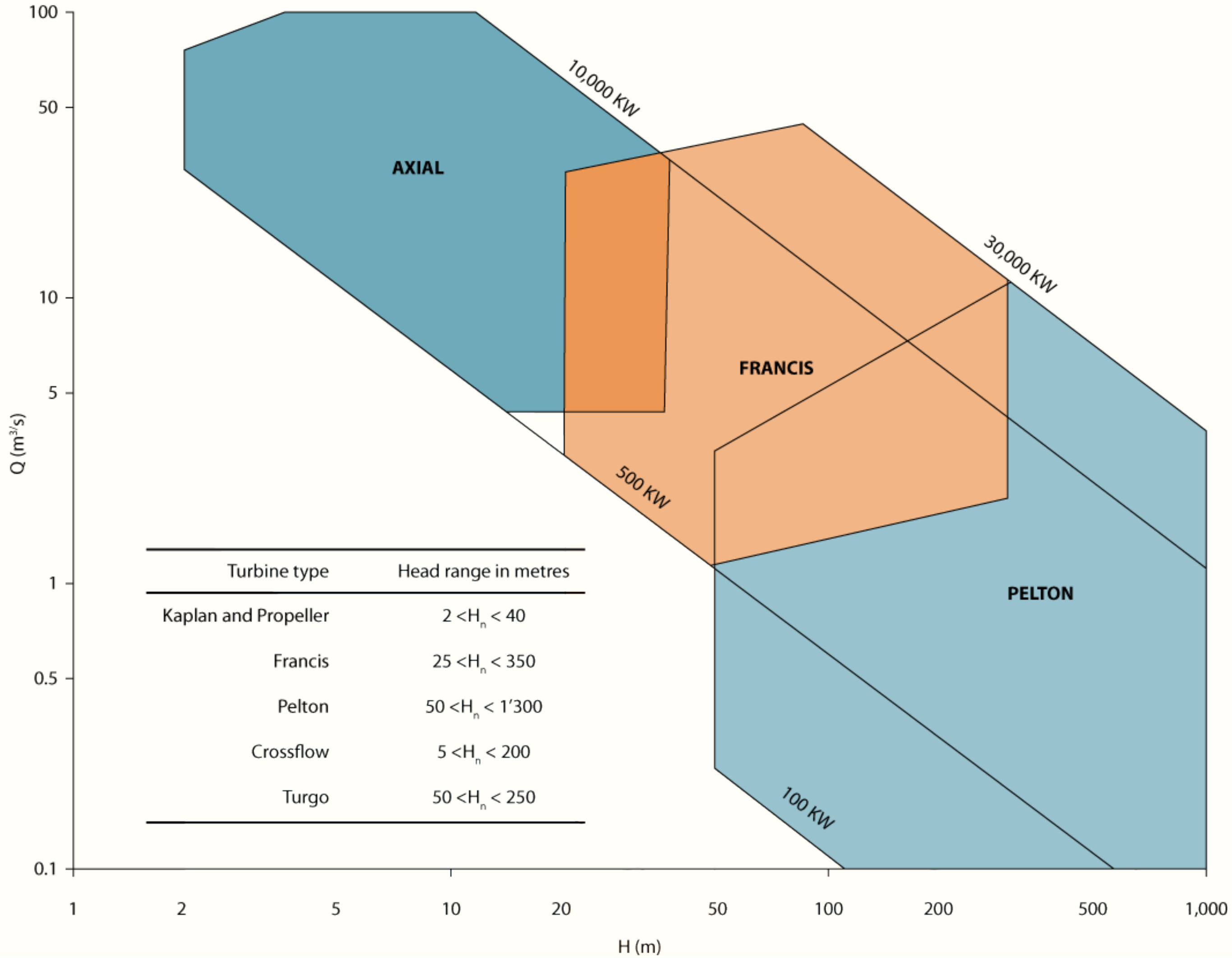
FDC for river with more steady flow

FLOW DURATION CURVE



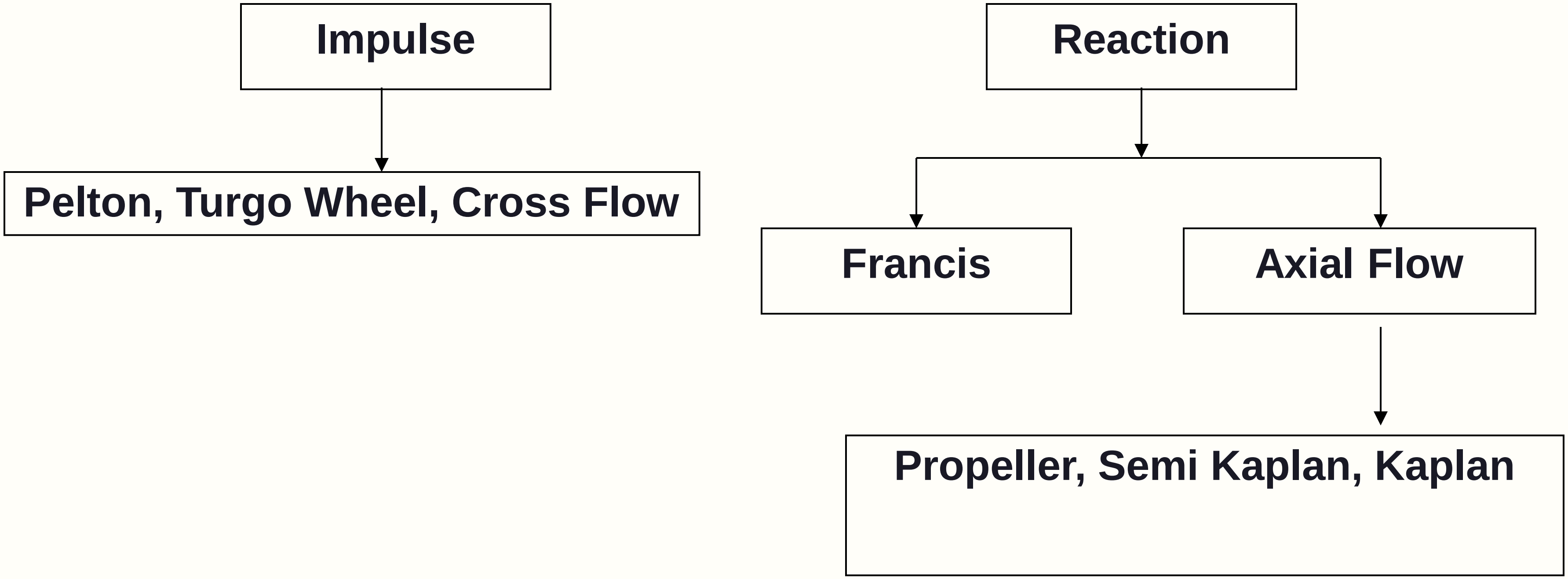
	No of days	% of the year
Flows of 8.0 m^3/s and greater	41	11.23
Flows of 7.0 m^3/s and greater	54	14.9
Flows of 6.5 m^3/s and greater	61	16.8
Flows of 5.5 m^3/s and greater	80	21.8
Flows of 5.0 m^3/s and greater	90	24.66
Flows of 4.5 m^3/s and greater	100	27.5
Flows of 3.0 m^3/s and greater	142	39
Flows of 2.0 m^3/s and greater	183	50
Flows of 1.5 m^3/s and greater	215	58.9
Flows of 1.0 m^3/s and greater	256	70
Flows of 0.35 m^3/s and greater	365	100

TURBINE SELECTION

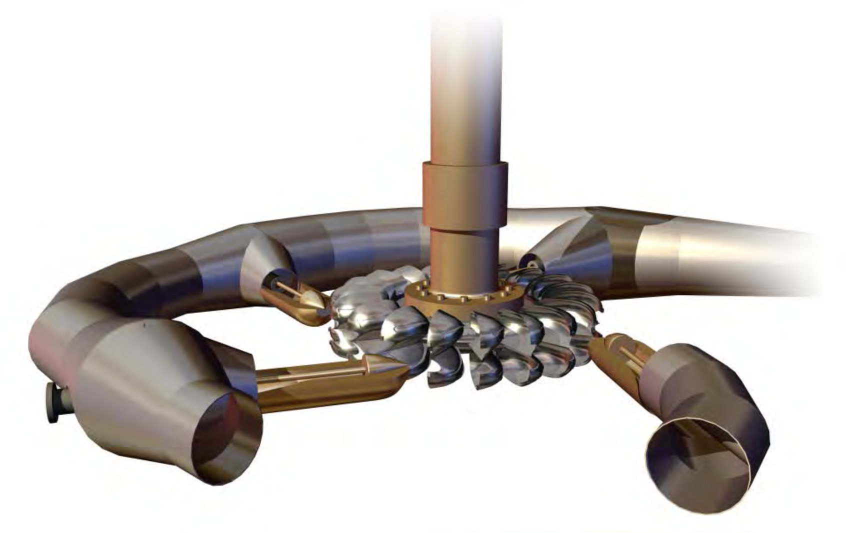


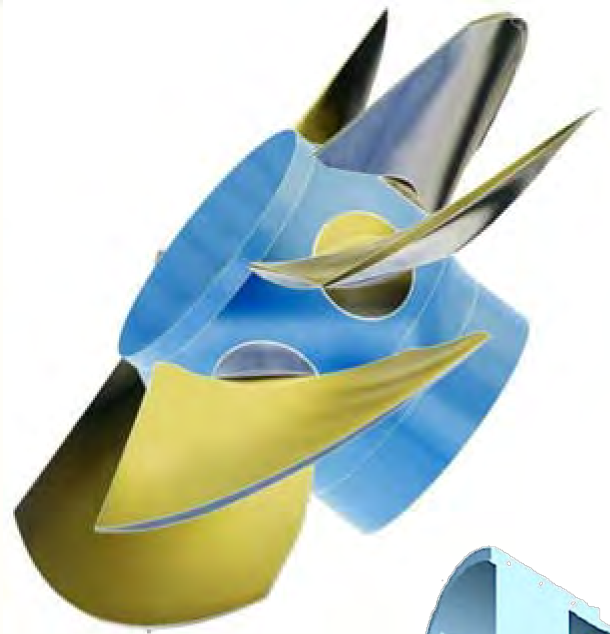
Turbine type	Head range in metres
Kaplan and Propeller	$2 < H_n < 40$
Francis	$25 < H_n < 350$
Pelton	$50 < H_n < 1'300$
Crossflow	$5 < H_n < 200$
Turgo	$50 < H_n < 250$

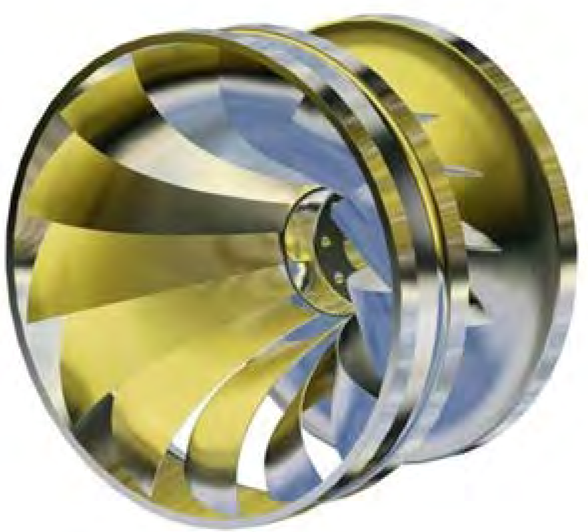
Turbine Classification

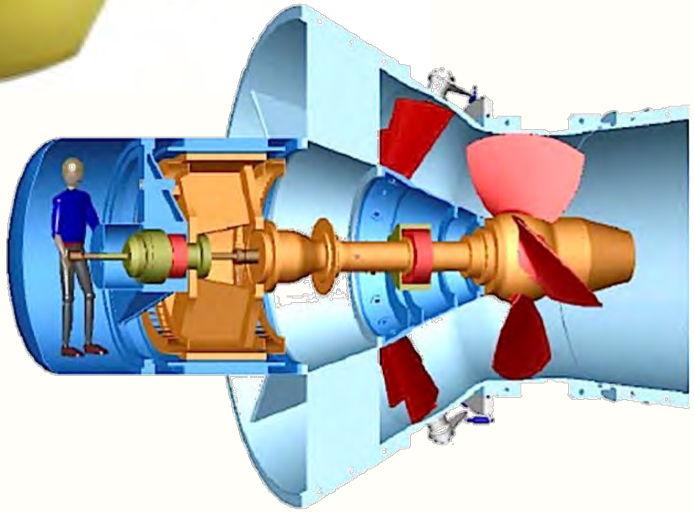


Turbine Types









NEW HYDROPOWER TECHNOLOGIES

IN STREAM {
- Water supply schemes
- Irrigation canals

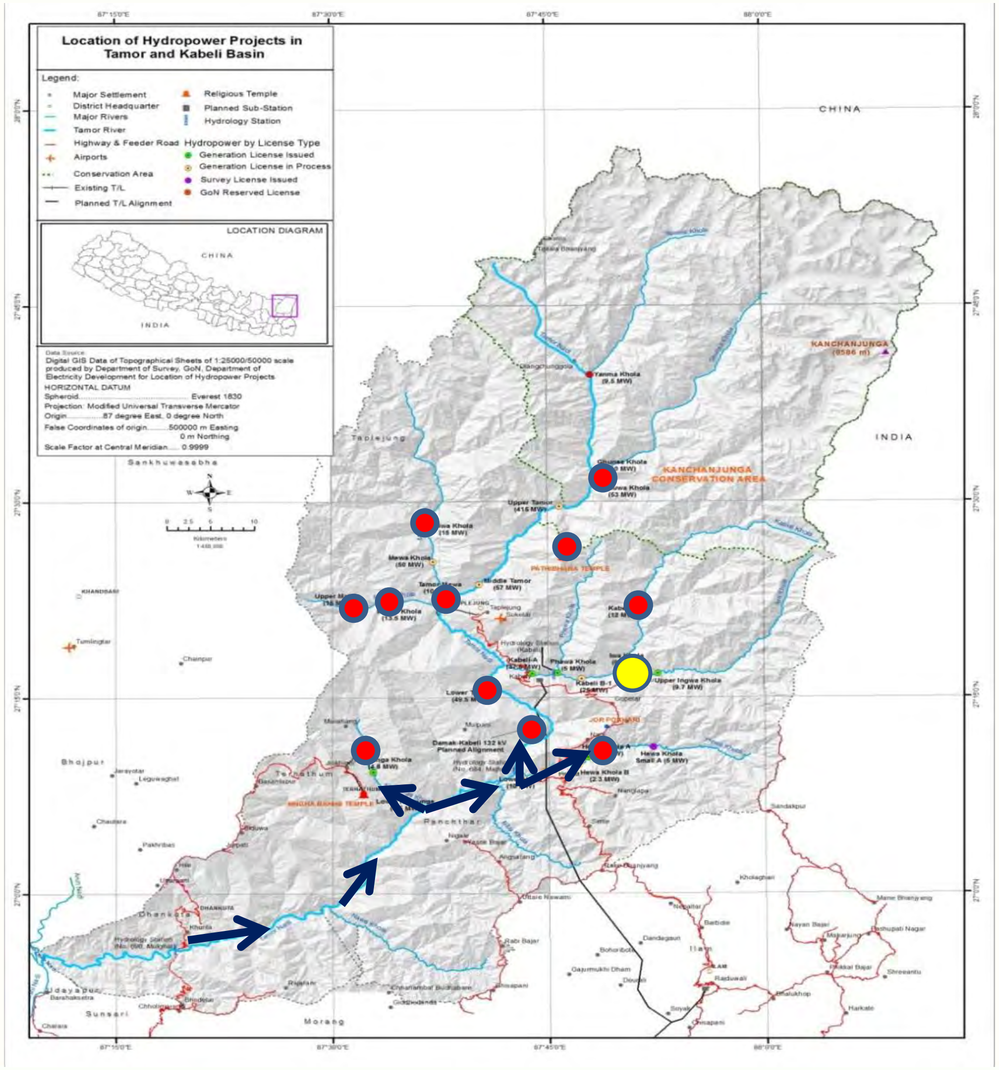
Hydro Kinetic

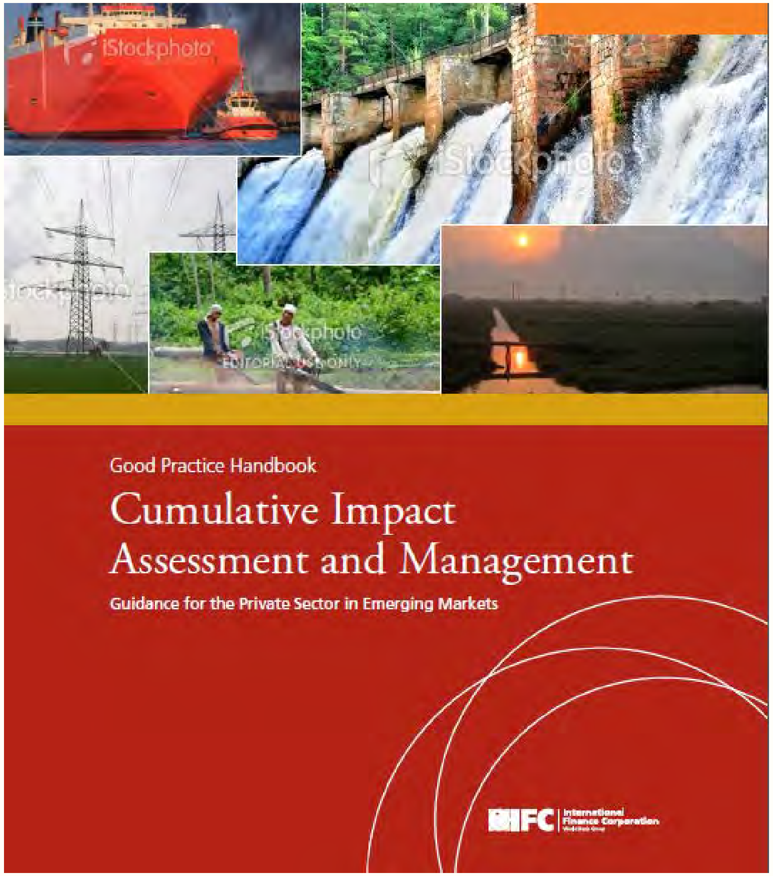
Kinetic energy of the current is captured

Courtesy of Hydro Green Energy, LLC Project at Hastings, MN

Hydro+™,

CUMULATIVE IMPACT ASSESSMENT





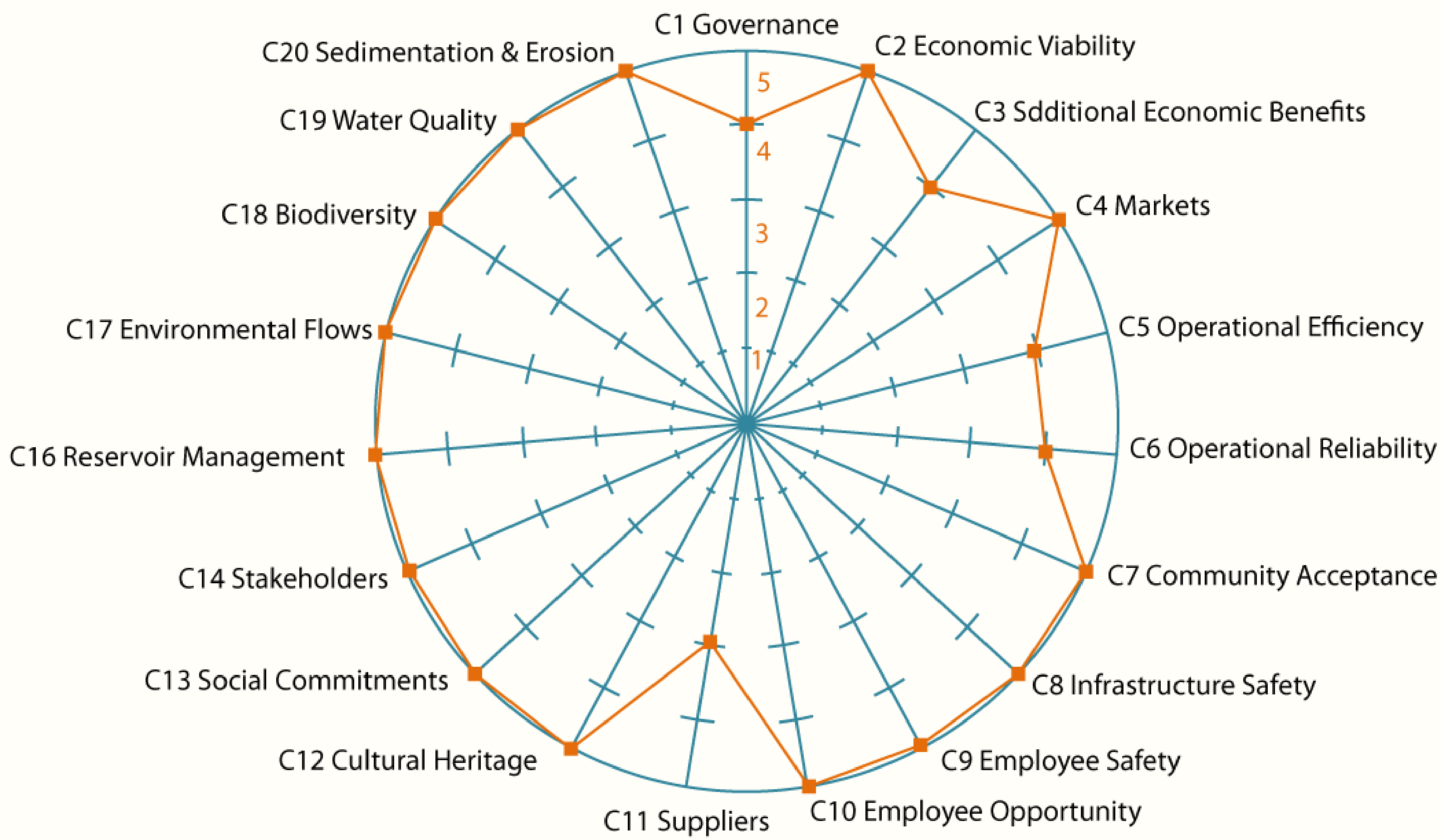
Proposed Small Hydros

Kabeli 'A' HPP

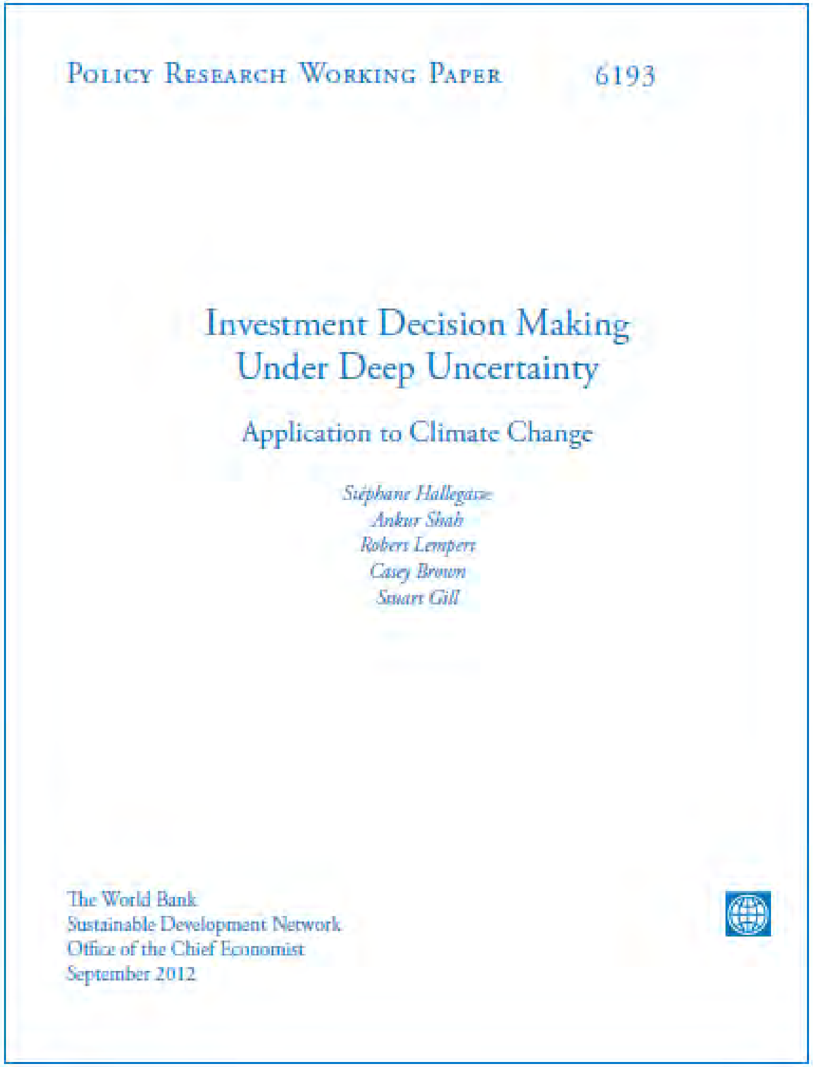
Fish migration route

SUSTAINABILITY
Assessment Protocol

Summery of scores for Blanda



CLIMATE CHANGE


POLICY RESEARCH WORKING PAPER 6193

Investment Decision Making Under Deep Uncertainty

Application to Climate Change

Stéphane Hallegatte
Ankur Shah
Robert Lempert
Casey Brown
Stuart Gill

The World Bank
Sustainable Development Network
Office of the Chief Economist
September 2012

IDA17: MAXIMIZING DEVELOPMENT IMPACT

Management screen all new IDA operations for short- and long term
climate change and disaster risks and, where risks exist, integrate appropriate resilience measures.

3. GLOBAL EXPERIENCES OF SMALL HYDROS LESSONS LEARNT

- Cost & time overruns
- Principles of headworks design & sediment management

COST & TIME OVER RUNS : CONTRACTS

Traditional Contracts

- Owner hires an engineer to design and the contractor builds.
- Most popular method in the public sector

EPC Contracts

- Linked to the development of the private sector in hydropower generation
- Promoted by some banks as a favorite
- Now current practice for hydropower projects implementation for both public & private Sectors

TRADITIONAL VS. EPC CONTRACTS

- Traditional (unit rate) contracts have the following inherent problems:
  I. *Design is separate from Construction.*
  II. *Variation orders lead to contractual disputes.*

- Turnkey contracts require more geotechnical information at the time of bidding than is normally available.

- EPCs are suitable for projects with no major unforeseen risks.

- EPCs have little employer involvement, the contractor takes total responsibility for the design and execution.

- EPCs are fixed price – Lump Sum. Interim and final payments are made without any certification: typically determined by reference to a Schedule of Payments.

CASE STUDY OF RISK MANAGEMENT: PROCESS STEPS

Basic Design by the Employer	Detailed design by the Contractor	Design Review Consultant
• Civil & Hydro Mechanical. • Detailed hydraulic and geo-technical design.	• Contractor responsible for the detailed design & structural design subject to the approval of Engineer.	• DRC responsible for review of the detailed design and drawings submitted by the Contractor.

TOC FOR THE STANDARD BIDDING DOCUMENTS

Part 1	**Bidding Procedures**
Section I	Instructions to Bidders
Section II	Bid Data Sheet
Section III	Evaluation and Qualification Criteria (Following Prequalification)
Section IV	Bidding Forms
Section V	Eligible Countries
Part 2	**Works Requirements**
Section VIA	General Specifications
Section VI B	Technical Specifications for Civil Works
Section VI C	Technical Specifications for Hydro-Mechanical Works
Section VI D	Quality Assurance Programme
Section VI E	Bid Drawings
Section VI F	**Risk Assessment and Risk Register, Geological Baseline Report, Schedule**
Section VI G	Annexures*
Part 3	**Conditions of Contract and Contract Forms**
Section VII	General Conditions (GC)
Section VIII	Particular Conditions (PC)
Section IX	Annex. to the Particular Conditions – Contract Forms

HEADWORKS: FIVE PERFORMANCE STANDARDS

Performance Standard	Consequences of Compliance Failure
1. Passage of all floods, including hazard floods	**Poor safety during flood time**
2. Passage of ice, trash, and floating debris	**Poor safety during normal operations**
3. Passage of sediments	
4. Bed control at intake	
5. Exclusion of suspended sediments and air	

HIGHER MAINTENANCE COSTS

BASU CHU, BHUTAN

ZEMRA ROR, TIGRAY, ETHIOPIA

JAGRAN, 30 MW

MELTING GLACIERS & GLOF

7,000 people, Khimti, airstrip and 18 villages along Tama Kosi, Sun Kosi.

SEDIMENT MANAGEMENT CRUCIAL

- Hydropower plants not sustainable without proper sediment management strategies

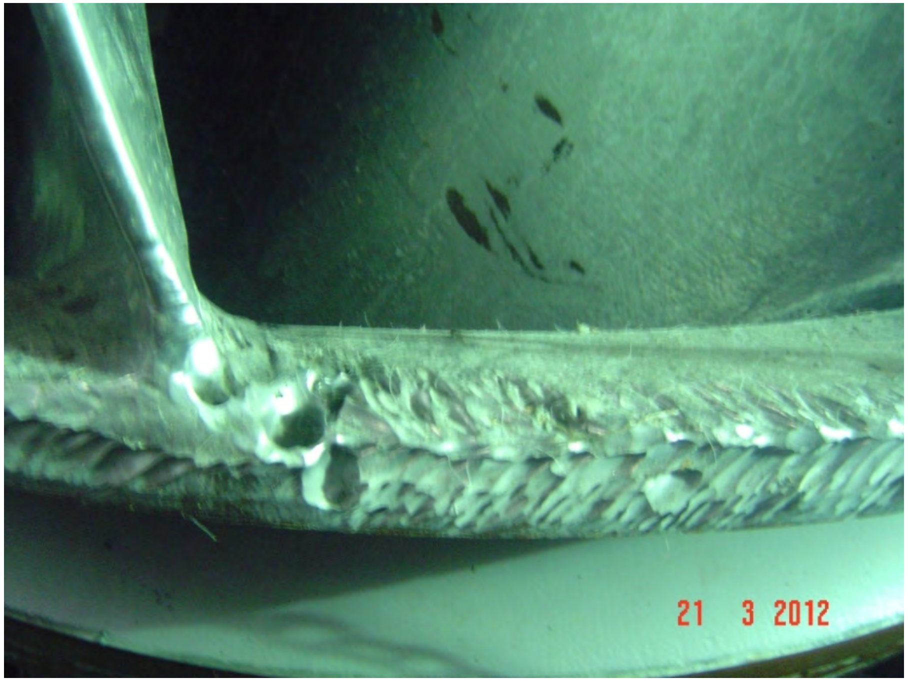
- Watershed management alone not sufficient – a combination of sediment management and watershed management strategies required

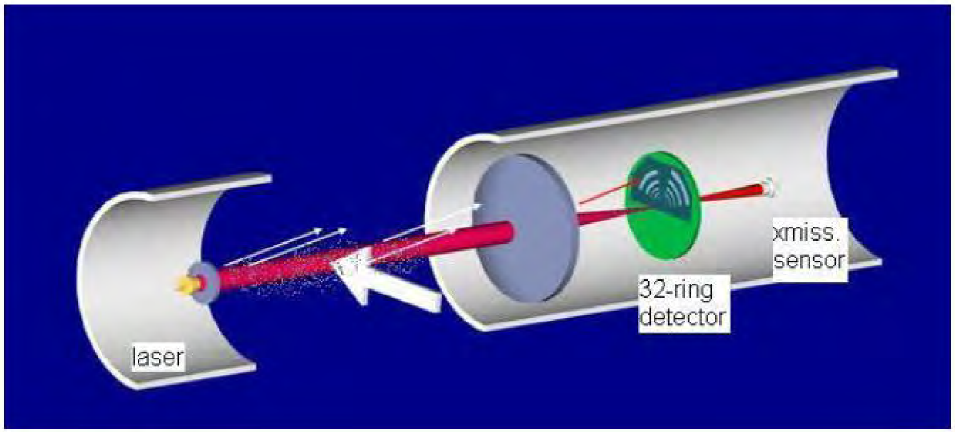
SEDIMENT GUIDED OPERATIONS

Optimum Sediment Exclusion (OSE) requires documentation and analysis of:

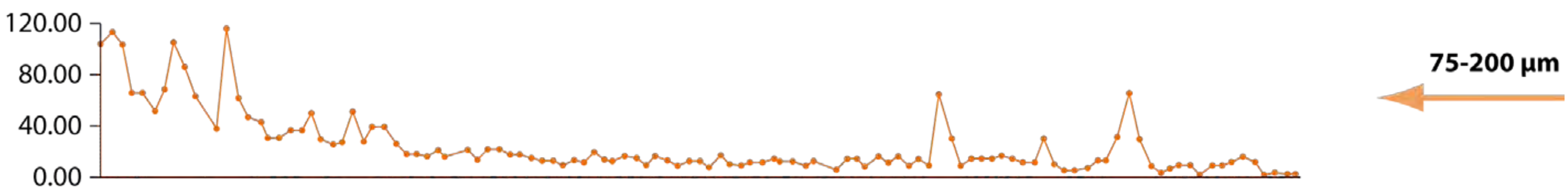
- time series of sediment data (grain size distribution and concentrations)
- corresponding effects on turbines
- associated costs due to the sediment induced problems

"Whilst Kali Gandaki "A" has been in operation since 2002 and thus is 11 years old, environmental issues such as sedimentation of the desanders are only now being felt."





Mass Concentration (PPM) of Particles between 75 to 200 Microns

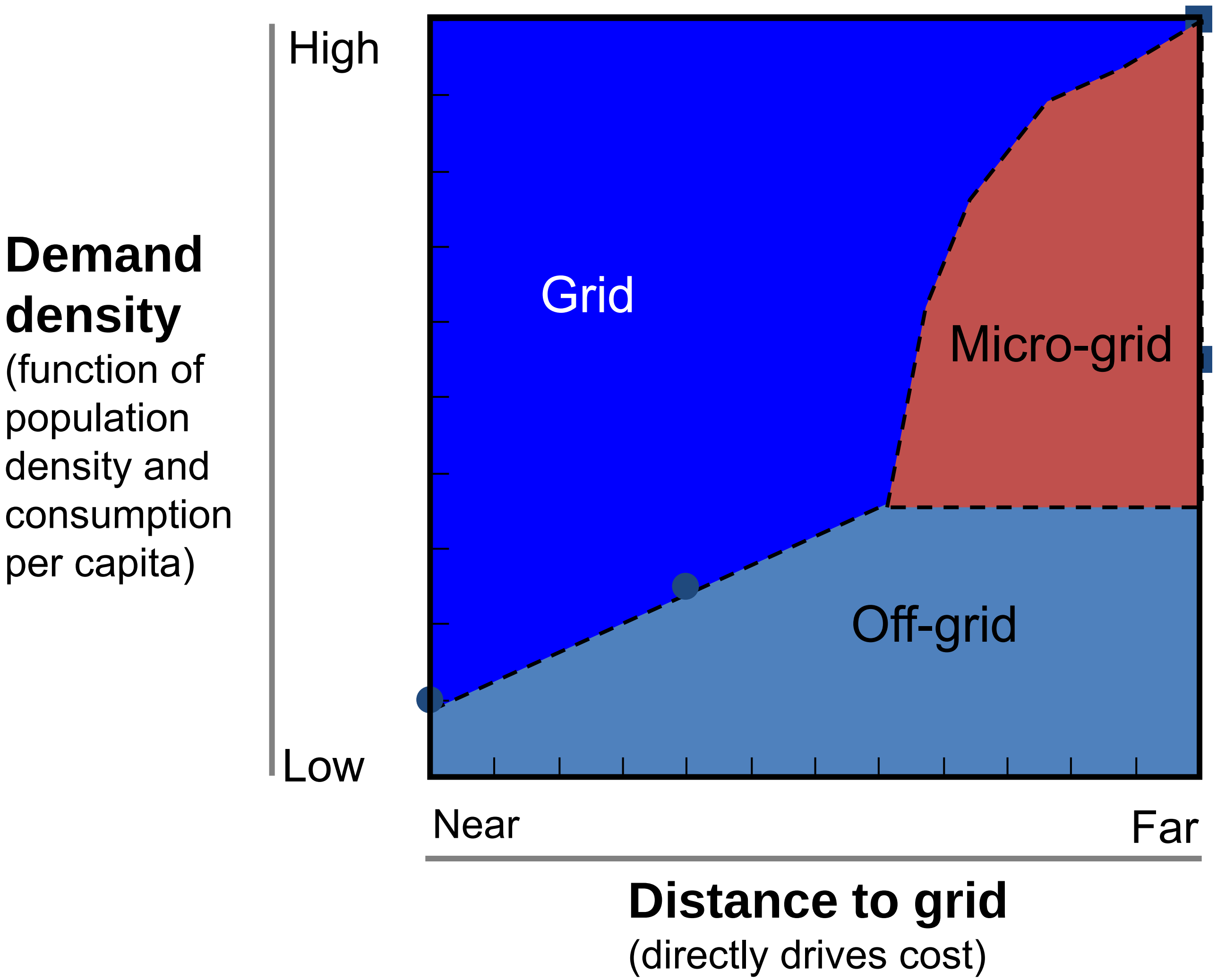


4. GRID OR OFF-GRID

Case Study of Andhi Khola Rural Electrification Plant

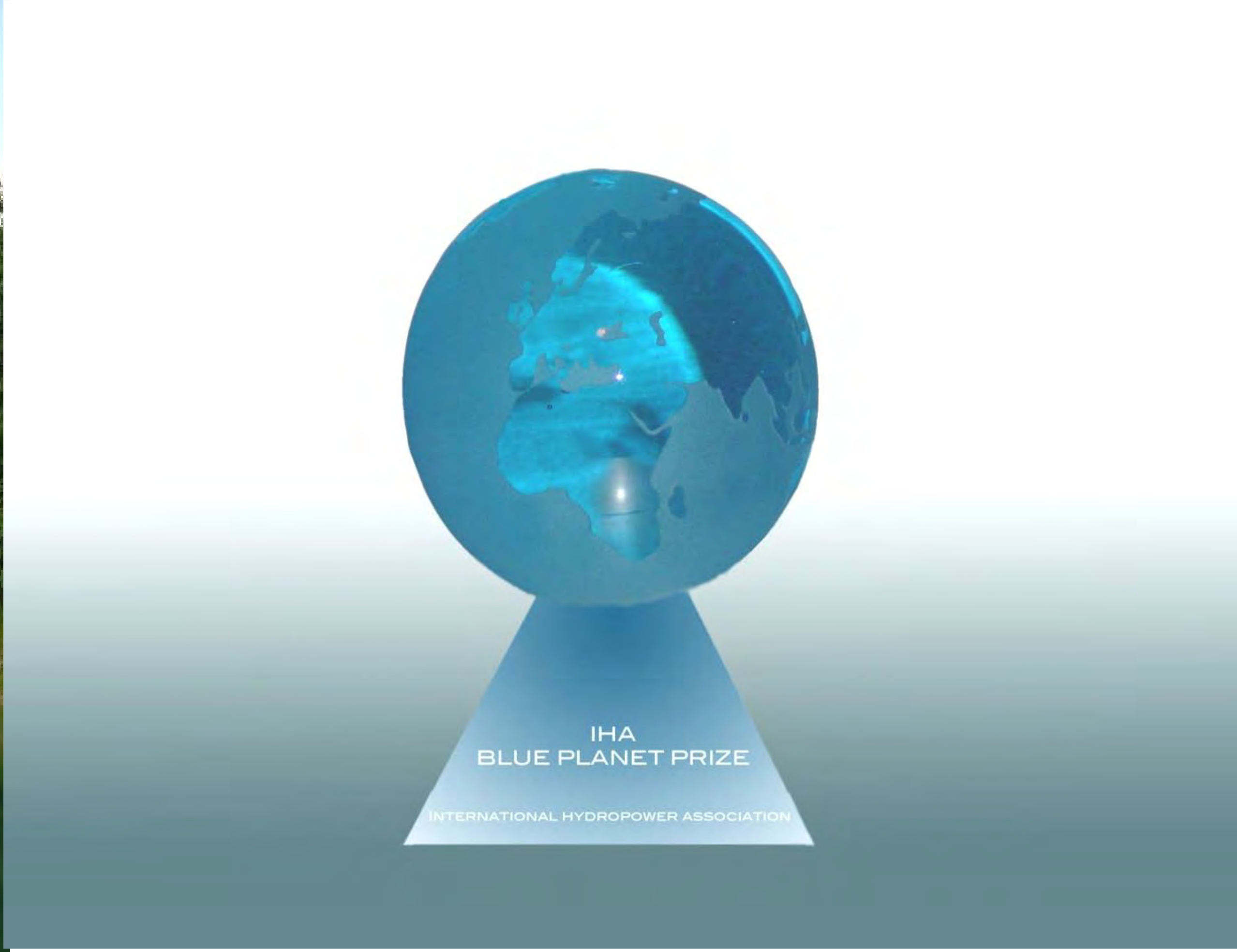
Case Study of Jhankre Mini Hydro Scheme

CONCEPTUAL



SOURCE: McKinsey & Company

2005 Blue Planet Prize



5 MW Andhi Khola Hydel and Rural Electrification Project

Recognised for excellence in socio-economic benefits and capacity building.

The Andhikhola Hydroelectric and Rural Electrification Project (AHREP)

- 5.1MW run of river scheme situated in the mid-hills in western Nepal
- 6m high concrete gravity dam
- 1.3 km long headrace tunnel and a 234 metre vertical drop shaft to an underground powerhouse
- 3 x 1.7 MW Pelton turbines and generators
- Produces 27 GWh of electricity connected to the local and national grid
- Success due to 2 factors – DISTRIBUTION & TARIFFS

- 80% of electricity users in the region are subsistence farmers
- Philosophy is to benefit low-income families in one of the poorest regions in the world.
- In contrast to most hydroelectric schemes in the country, which provide power to urban communities that are often remote from the project site, the aim of the project was to make electricity available to rural communities close to the project site.
- Within the project area, over 17,000 consumers of electricity across 22 villages benefit from the scheme, with this number growing by 10% annually.

Intermediate 1kV distribution voltage

Found to be very economical in supplying areas where the population is less dense. This is largely because a single porter can carry transformers to areas that are not serviced by roads, significantly reducing access costs.

Innovative power transmission poles

Lightweight poles consisting of tapered telescopic sections were developed. These are carried by porters to areas not serviced by roads and are assembled on site.

Use of insulated cables

The introduction of insulated cables enabled distribution lines to be suspended from wooden poles, live trees and buildings, further reducing the cost of transmission.

Low cost wiring

The cost of wiring houses using conventional methods (1990's prices) was approximately USD$20-30, which is prohibitively expensive for most families within the project area. The development of easy to install wiring harnesses brought this cost down to around USD$5 per household.

Tariff structure

Families subscribe to 25-400W usage at a fixed tariff. Larger consumers of electricity are equipped with two tier meters. Usage above the subscribed demand is charged at a significantly higher rate, which aids in reducing peak demand.

Low wattage electric cookers

The introduction of low wattage electric cookers for off-peak cooking saving trees.

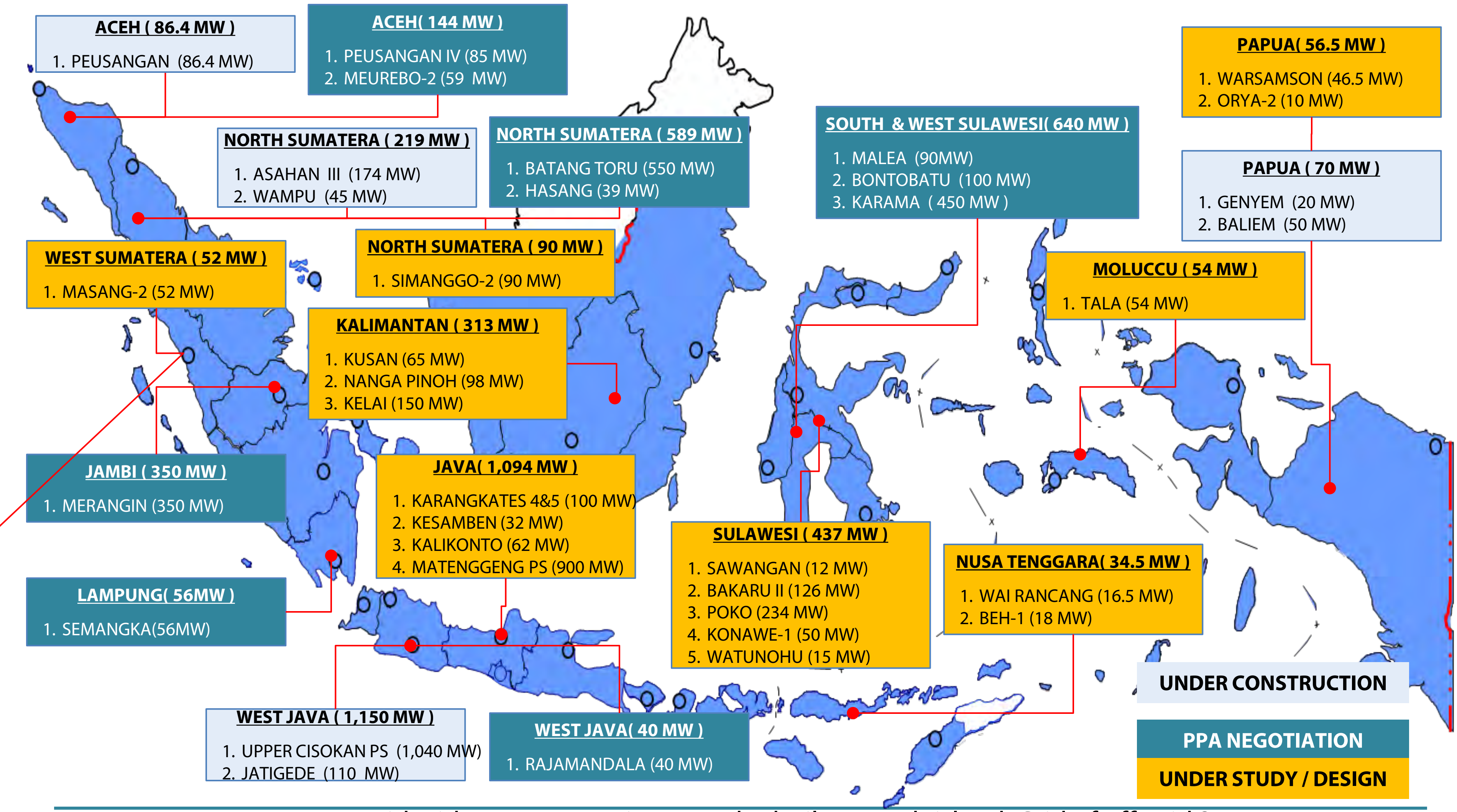
Local Capacity Building

- Local employment & skills development
- Birth of BPC, Himal Hydro & NHE

Multiple Use Benefits

- Irrigation benefits via gravity irrigation of 280ha of land
- 800 subsistence households go from famine to three harvests
- Sale of excess crops provide extra income

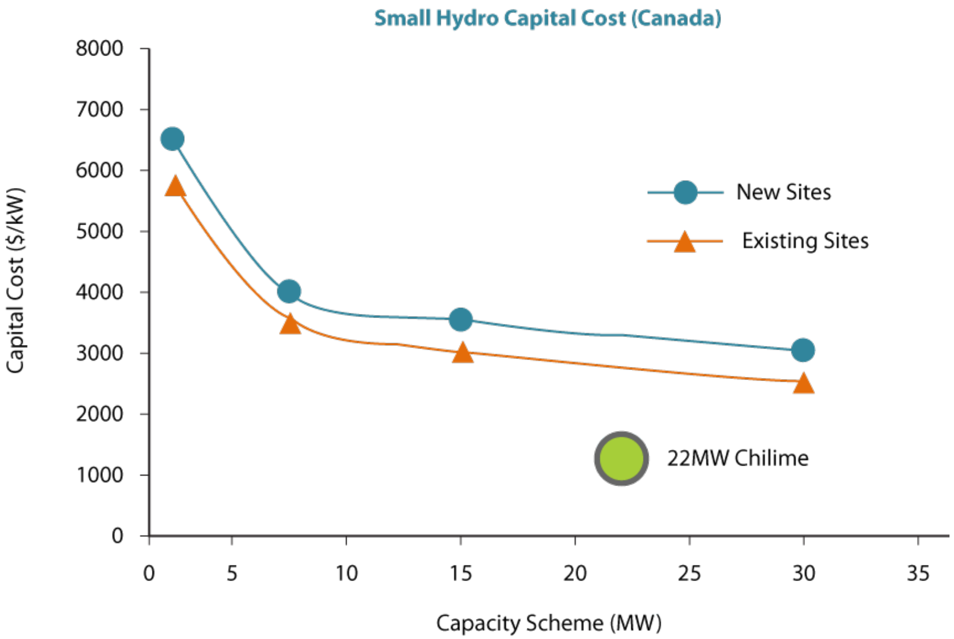
- 635 kW Jhankre supplied construction power to 60 MW Khimti HPP.
- Handed over from HPL to the Khimti Rural Electric Cooperative (KREC) established in 2004 as its CSR.
- KREC is the first fully independent, democratically operated and locally managed rural electric cooperative in the country.
- It gives green renewable electricity to 4,600 households.
- A locally managed rural electric cooperative.
- KREC helps locals with health care, small industry and enterprises and access to modern communications.
- Benefits reach over 40,000 people.



a new grid with new generation must be built on each island. Grid of off-grid ?

5. FINANCING OF SMALL HYDROS

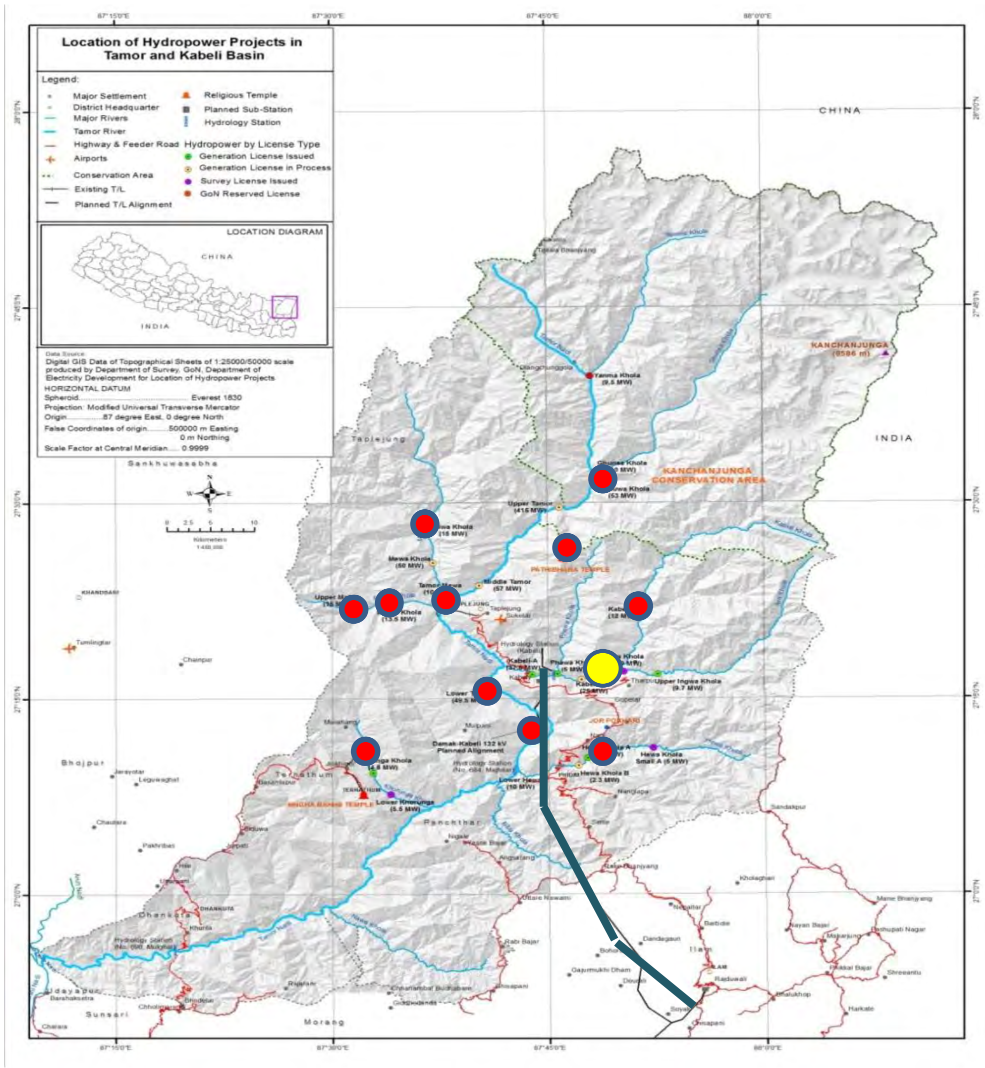
Component	Costs
Civil	40-60%
Electromechanical	20-40%
Environmental	10-20%
Transmission	10-15%
Engineering	8-10%



Adjusted to 2008 dollars

	INSTALLED (USD/kW)	OPERATIONS AND MAINTENANCE COST (% / YEAR OF INSTALLED COSTS)	CAPACITY FACTOR %	LEVELISED COST OF ELECTRICITY (2010 USD/kWh)
Large hydro	$1,050-$7,650	2-2.5	25 to 90	0.02-0.19
Small hydro	$1,300-$8,000	1-4	20 to 95	0.02-0.27
Refurbishment/ upgrade	$500-$1,000	1-6		0.01-0.05

RISK	STAGE	MITIGATION
Availability of water: hydrological risk	Operation mainly	Low flow and high flows (monsoon floods) Better data; risk sharing with the Government
Flooding of powerhouse: hydrological risk	Construction/ Operation	Better engineering
Maintenance neglected: control systems not working; safety instruments not working	Operation	Operation staff must be well supported from head office; Strong organizational structure needed.
Operation: sediment management	Operation	Coanda intake; settling basin properly designed; monitoring
Plants do not generate as planned	Operation	Small unknown manufacturers
Power evacuation	Operation	Transmission lines must be in place to evacuate the power
Geotechnical	Construction	Underground works
Contractual	Construction (disputes)	
Labor disputes/political risks/Offtaker risks	Construction	Political guarantee instruments ; comfort letter from Govt



The World Bank

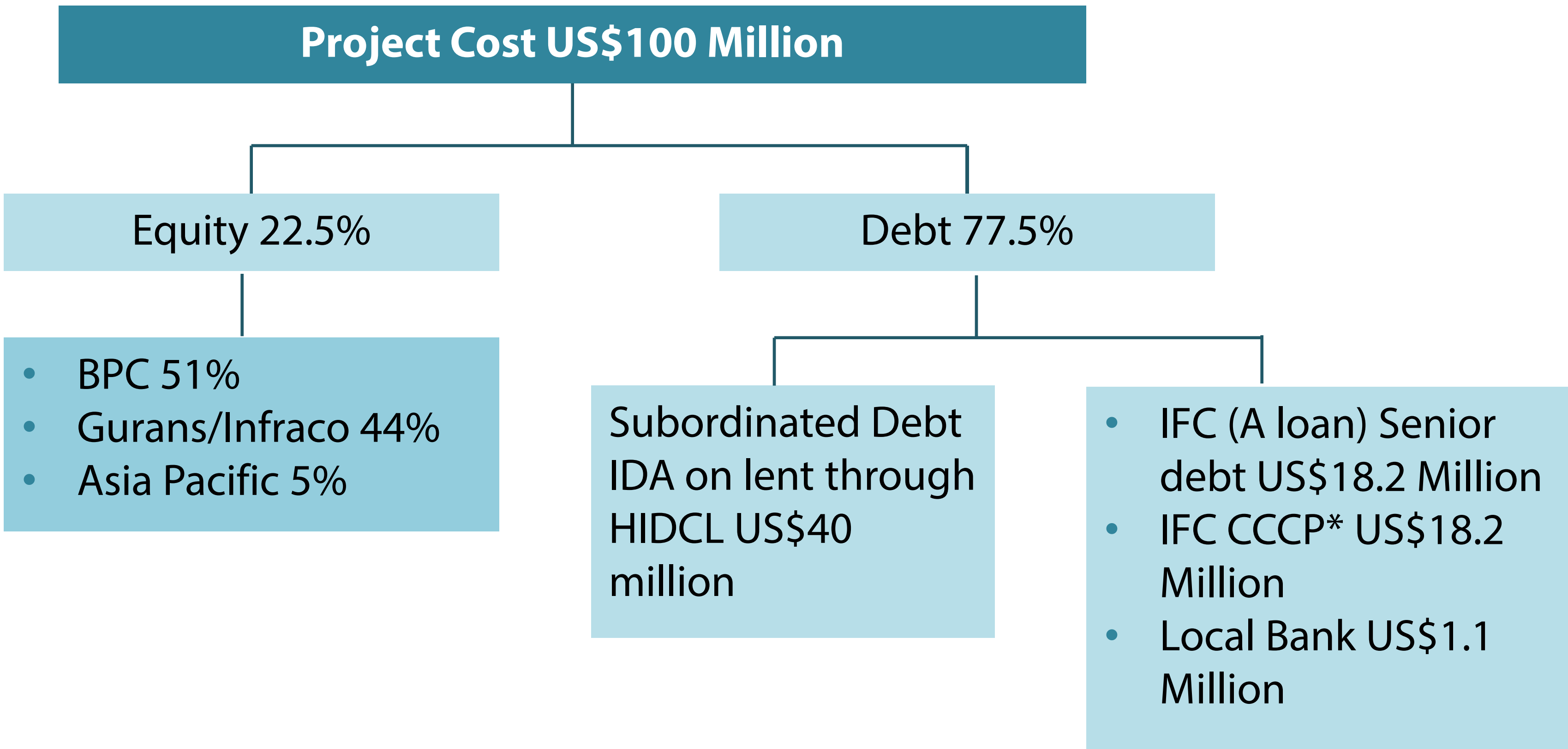
International Finance Corporation
World Bank Group

Proposed Small Hydros

Kabeli 'A' HPP

132 KV Transmission Line

- 37.6MW peaking ROR
- Located in Panchthar District, Eastern Development Region
- Developed by Butwal Power Company, an existing IFC client
- Held in SPV called Kabeli Energy Limited (KEL)
- Awarded to KEL by Gov't of Nepal through competitive bidding
- 35 year concession period; BOOT model
- 25 year PPA with NEA



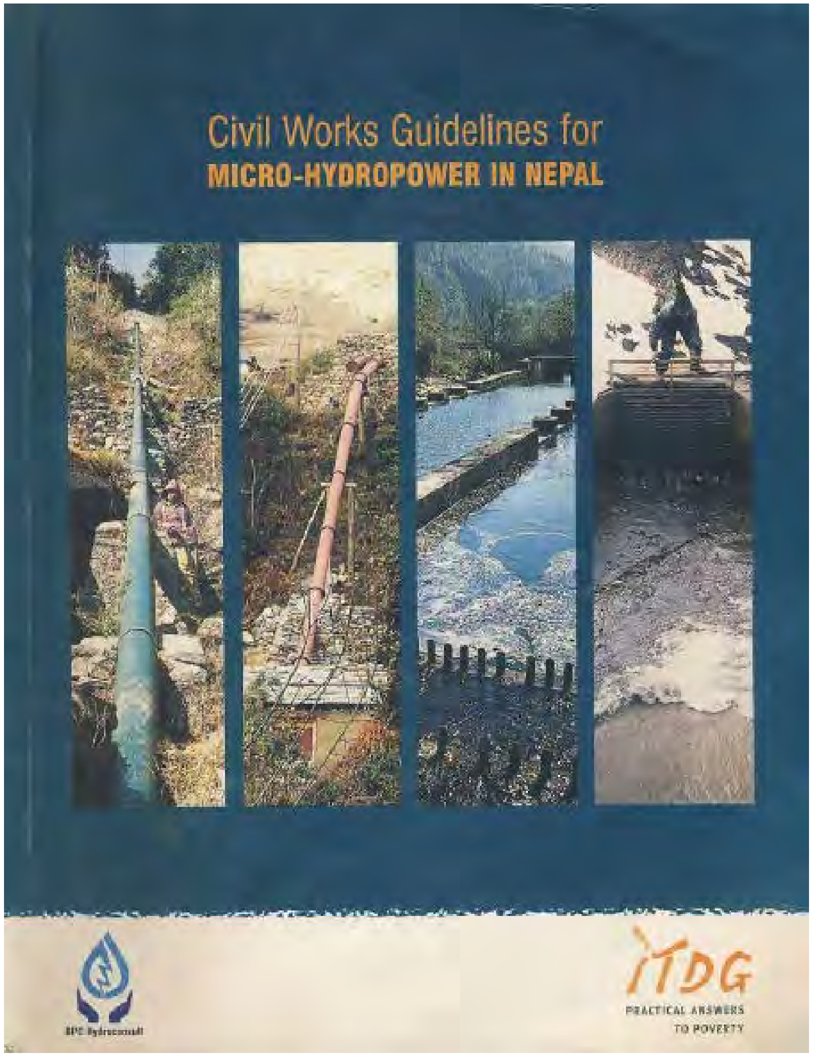
* Canada Climate Change Program

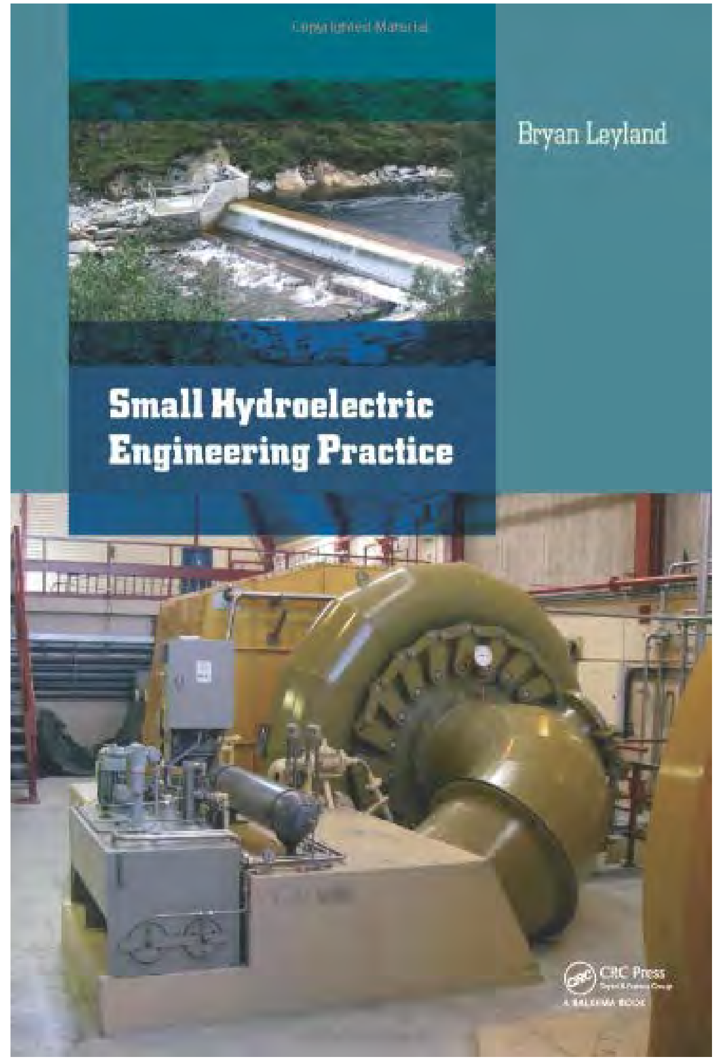
6. REMOVING BARRIERS

Recommendations from Alliance for Rural Electrification

- RESOURCE MAPPING. Expand the **availability of data** on potential sites and meteorology.
- Amend policies and legislation on **electricity tariffs, subsidies and concessions.**
- Further develop **preferential policies.** e.g. tax reductions, easy imports, soft loans and grants as well as encouraging private firms to invest in SHP schemes
- Establish **policy targets for SHP** and raise awareness on its importance. An action plan should be established that sets out a roadmap facilitating and monitoring the process.
- Further develop **specific support funding/finance schemes for SHP** and/or technical assistance to the banking and microfinance sectors.
- Invest in **capacity building** so that local communities better understand SHP, taking **best practices** into account.

Source: Alliance for Renewable Energy (ARE)


Civil Works Guidelines for
MICRO-HYDROPOWER IN NEPAL
ITDG
PRACTICAL ANSWERS
TO POVERTY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Bryan Leyland
Small Hydroelectric
Engineering Practice
CRC Press

REFURBISHMENT PROJECTS GENERALLY FALL INTO TWO CATEGORIES:

Life extension. Equipment is replaced on a "like for like" basis and little effort is made to increase capacity → 2.5% gain in capacity.

Upgrades. Increased capacity and efficiencies. Increased cost can be justified by increased revenues → 10%-30% gain in capacity.

Pre-Feasibility Study	Purpose Desk Study Site Assessment	Hydrology Topography Geology	Two Critical Values Environmental Assessment Economic Analyses
Feasibility Study	Additional Site Assessment Hydrology Topography	Geology Time Schedule Environmental Assessment	Economic Analyses Financial Arrangements
Detailed Design	General Civil Works Metal Works	Electromechanical Works Distribution Lines	
Tendering	Contract Structure Tender Preparation Bid Invitation	Bid Evaluation Contract Negotiations Contract Award	
Implementation Action	Periodic Review Contracts Co-ordination Site Activities	Civil Works Metal Works Distribution Lines	Electromechanical Works
Operation & Maintenance	O & M Personnel Preventive Maintenance Maintenance by OEM	Spare Parts	

Administrative Issues/Permits & Licenses

ANDRITZ