WATERPOWER
HYDRO BASICS

JULY 15-16, 2024

COLORADO CONVENTION CENTER
DENVER, COLORADO

CO-LOCATED WITH

HYDROVISION INTERNATIONAL

WATERPOWER HYDRO BASICS
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Waterpower Hydro Basics Overview

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Monday Morning

0815 - 0840	Introduction	
0840 - 0900	Session #1	Hydro Overview
0905 - 1005	Session #2	Harnessing the Water
Break		
1020 - 1120	Session #3	Turbine Basics
1125 - 1225	Session #4	Generator & Electrical Sys Basics
Lunch		

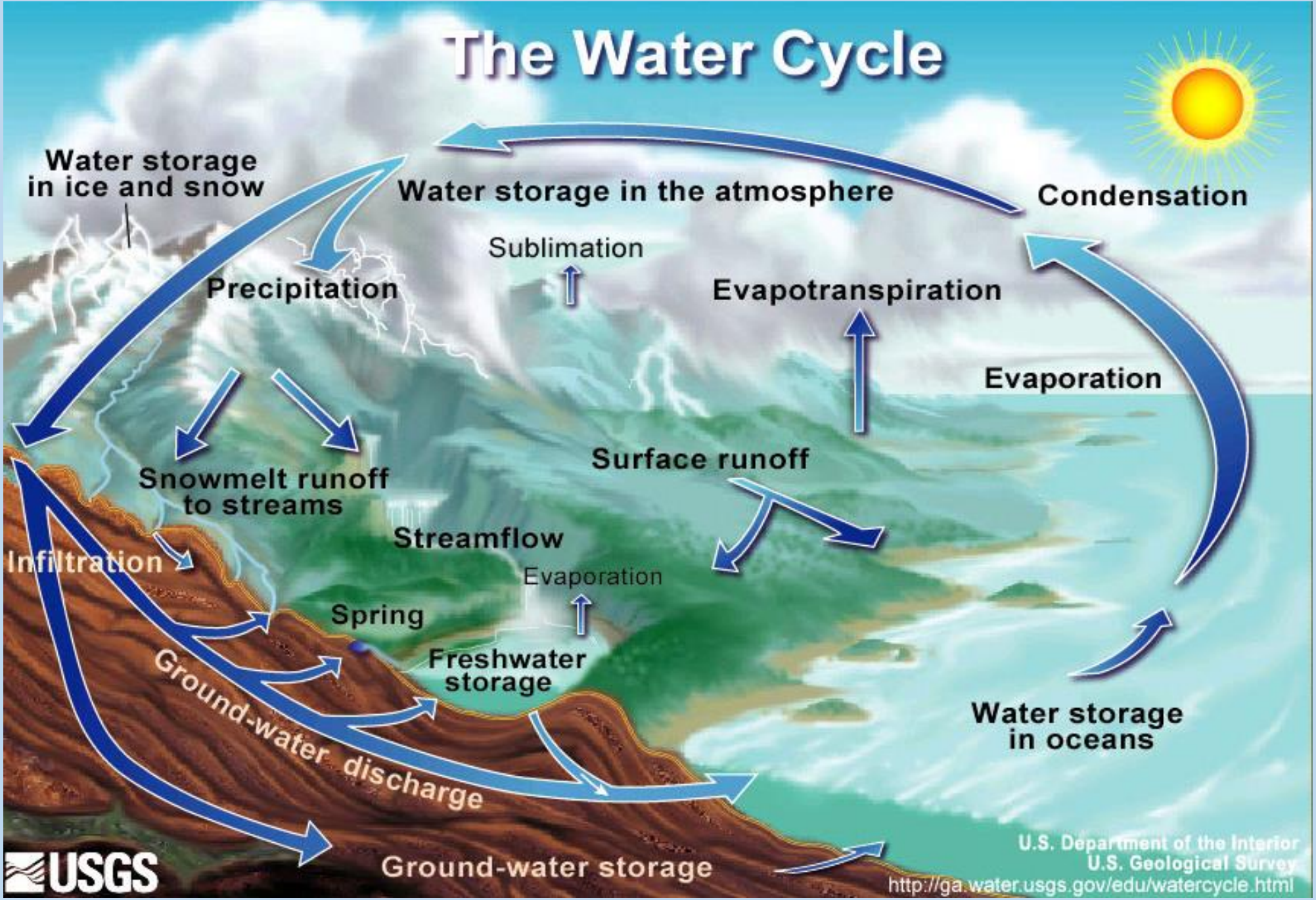
Monday Afternoon

1340 – 1440	Session #5	Hydro in a Power System
1445 – 1545	Session #6	Day to Day Hydro Operations
Break		
1605 – 1650	Session #7	Natural Resource Stewardship
1655 – 1700	Recap	

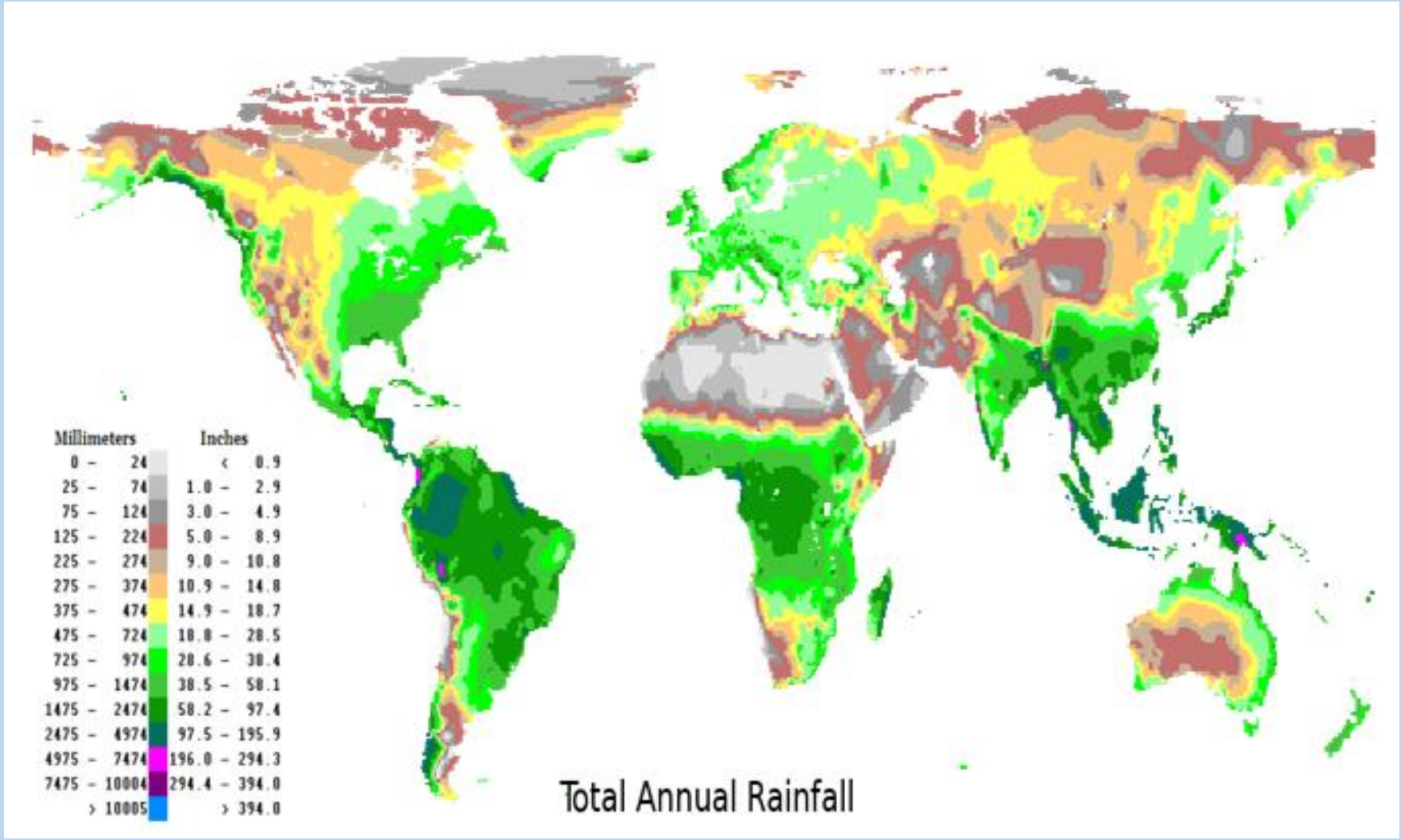
Tuesday Morning

0800 – 0830	Warmup and Stretching
0830 – 0915	Session #8 **Dams & Water Quality**
0920 – 1020	Session #9 **How Projects are Regulated**
Break	
1035 – 1135	Session #10 **Communicating Hydro's Value**
1140 – 1230	Course Wrap-up

introduction


The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Surface runoff
Snowmelt runoff to streams
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
USGS
U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html

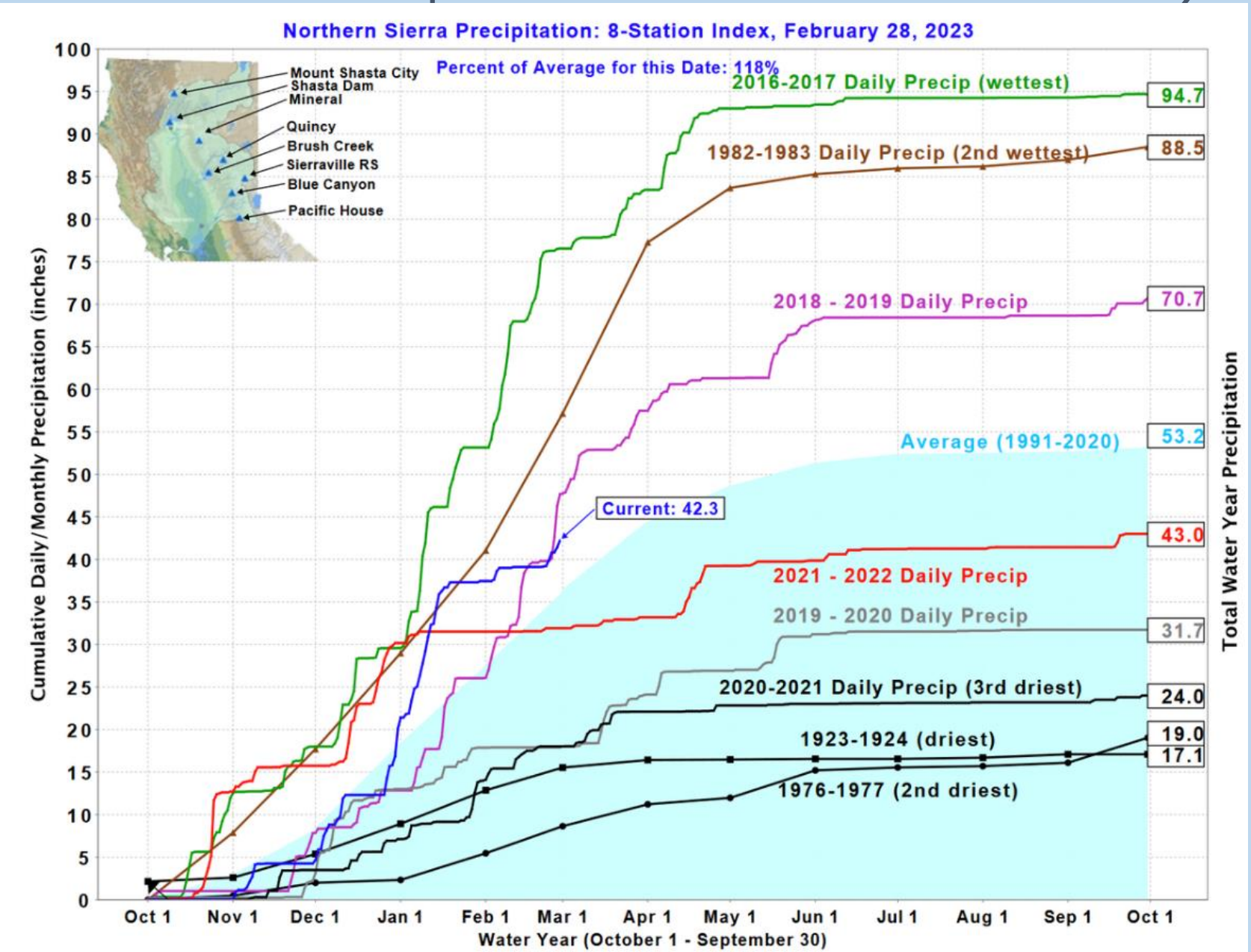
What Nature Gives Us | *Geographic Fuel Variability*



Source: NOAA, rainfall distribution 2010

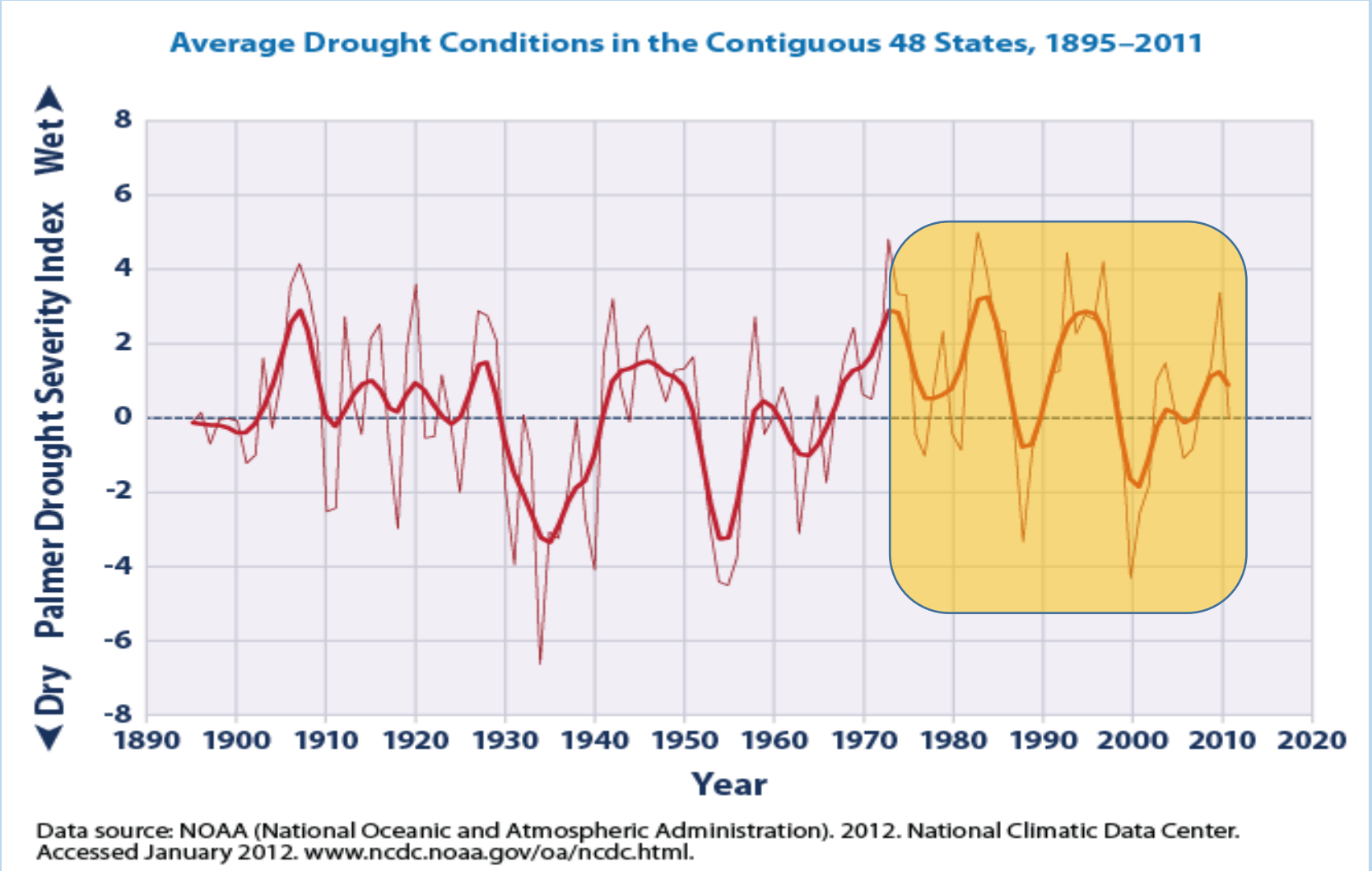
What Nature Gives Us | *Runoff Variability*

What Nature Gives Us | *Annual & Seasonal Fuel Variability*



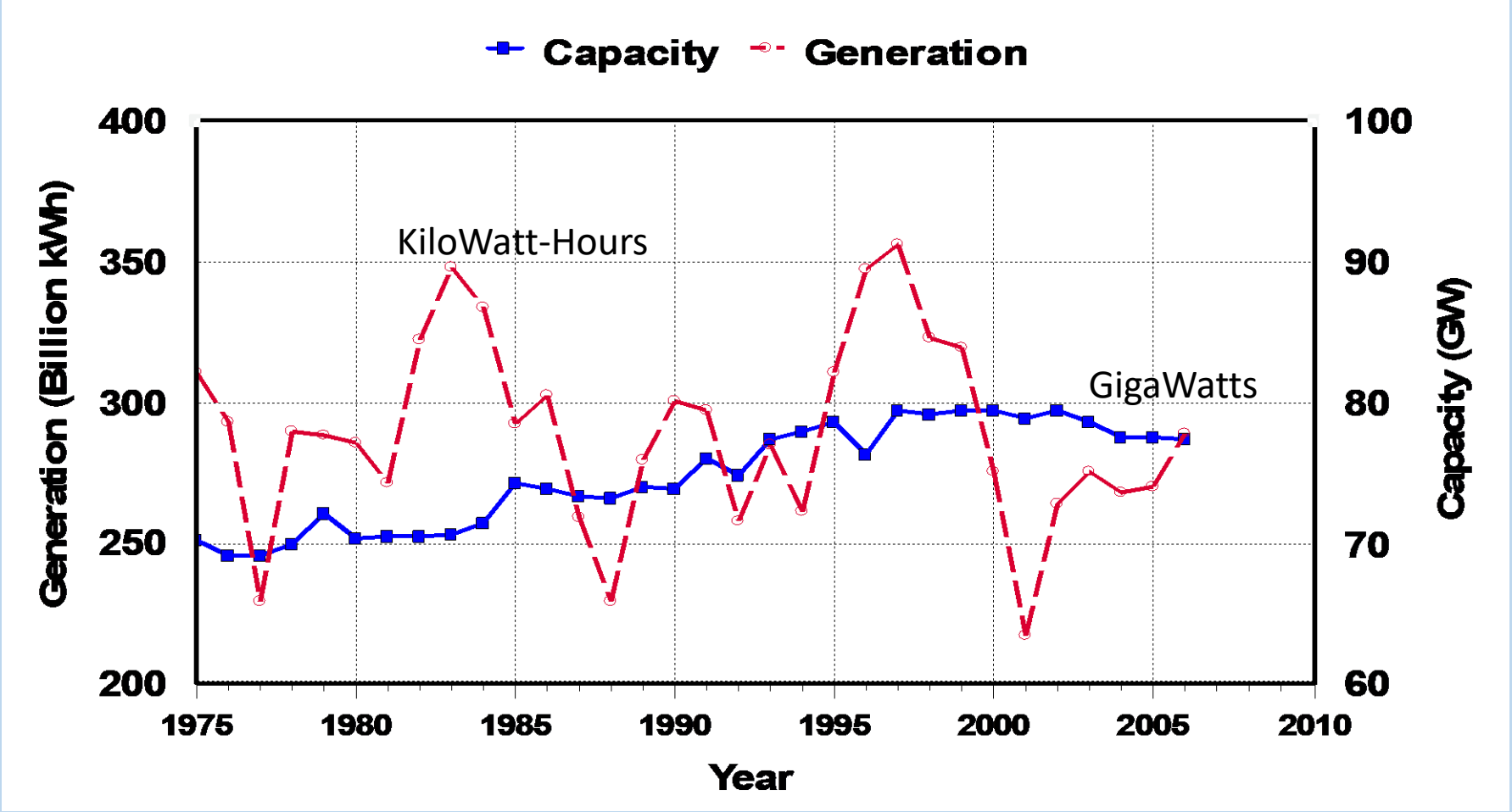
US Hydropower Capacity and Generation

Historical trends in Capacity and Generation

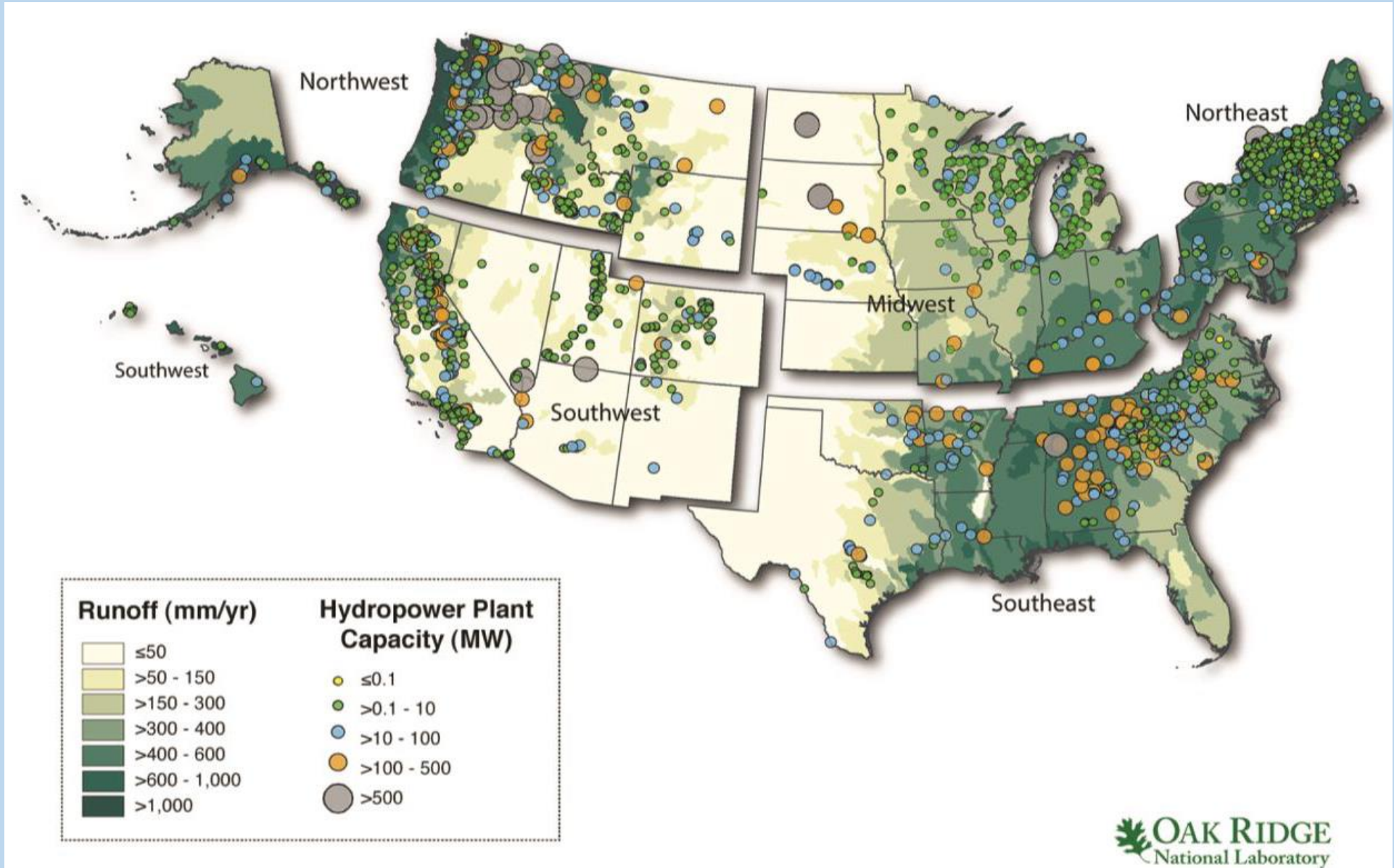


US Hydropower Capacity and Generation

Historical trends in Capacity and Generation

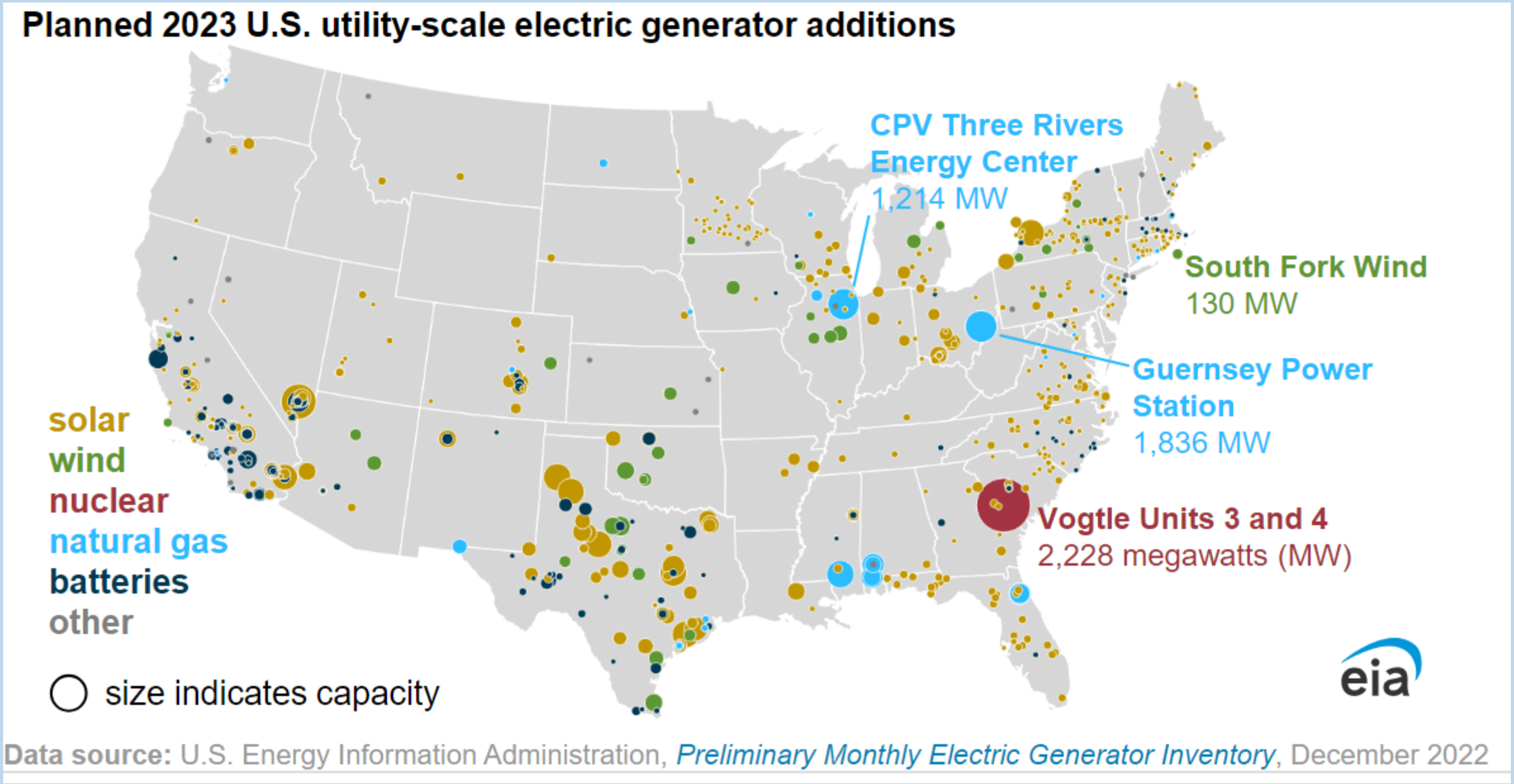


What Nature Gives Us | *Runoff to Generation*



OAK RIDGE National Laboratory

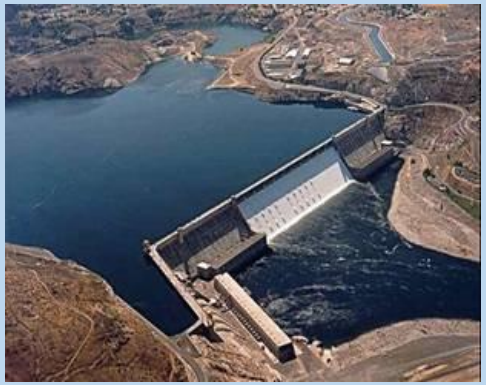
FUNDAMENTALS


Planned 2023 U.S. utility-scale electric generator additions
CPV Three Rivers Energy Center
1,214 MW
South Fork Wind
130 MW
Guernsey Power Station
1,836 MW
Vogtle Units 3 and 4
2,228 megawatts (MW)
solar
wind
nuclear
natural gas
batteries
other
size indicates capacity
eia
Data source: U.S. Energy Information Administration, Preliminary Monthly Electric Generator Inventory, December 2022

harnessing the power

How Hydroelectric Power Is Harnessed

- Elevation difference creates head pressure and water motion.
- Created by natural geography or by dams.



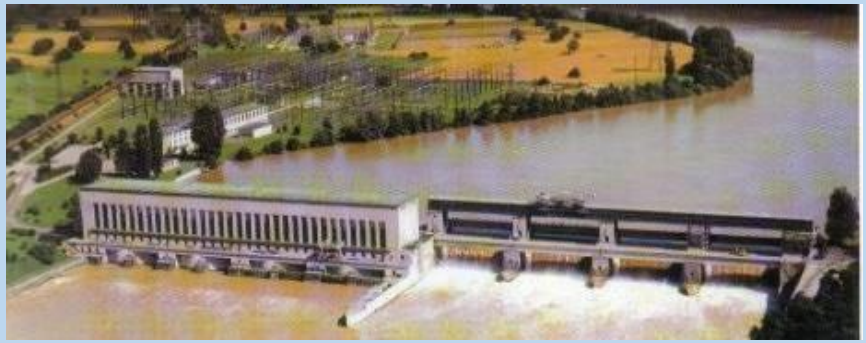
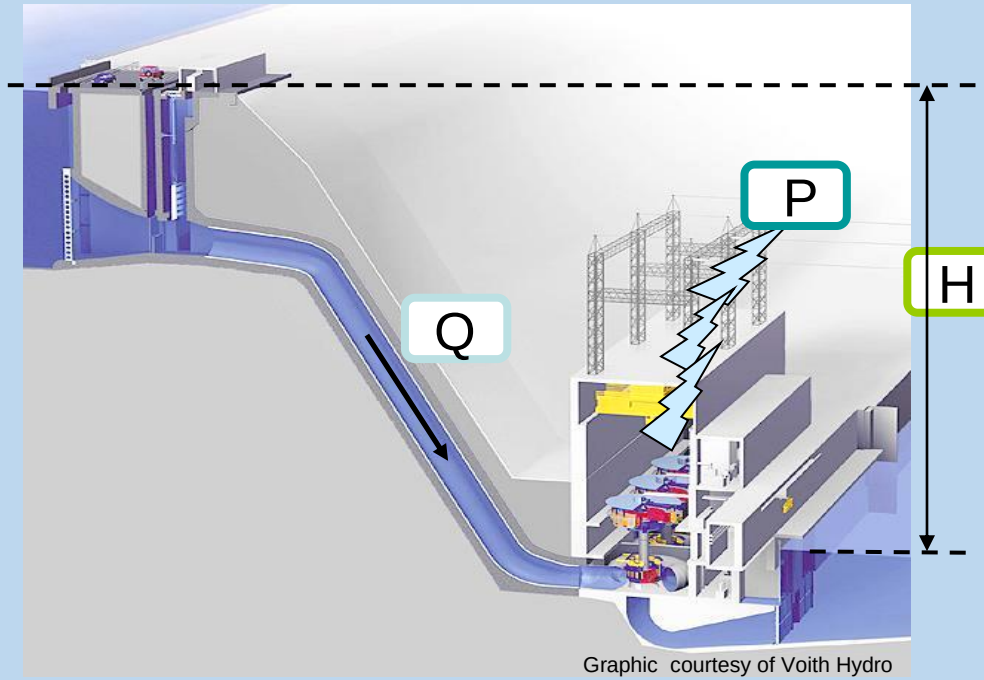


Photo courtesy of Voith Hydro

Convert the Potential Energy of Water at Elevation to Kinetic Energy Delivered to the Turbine

- Elevation difference (head) creates the water flow
- Turbines are used to convert hydro into electrical energy



Power = f (Head, Discharge, K_L)

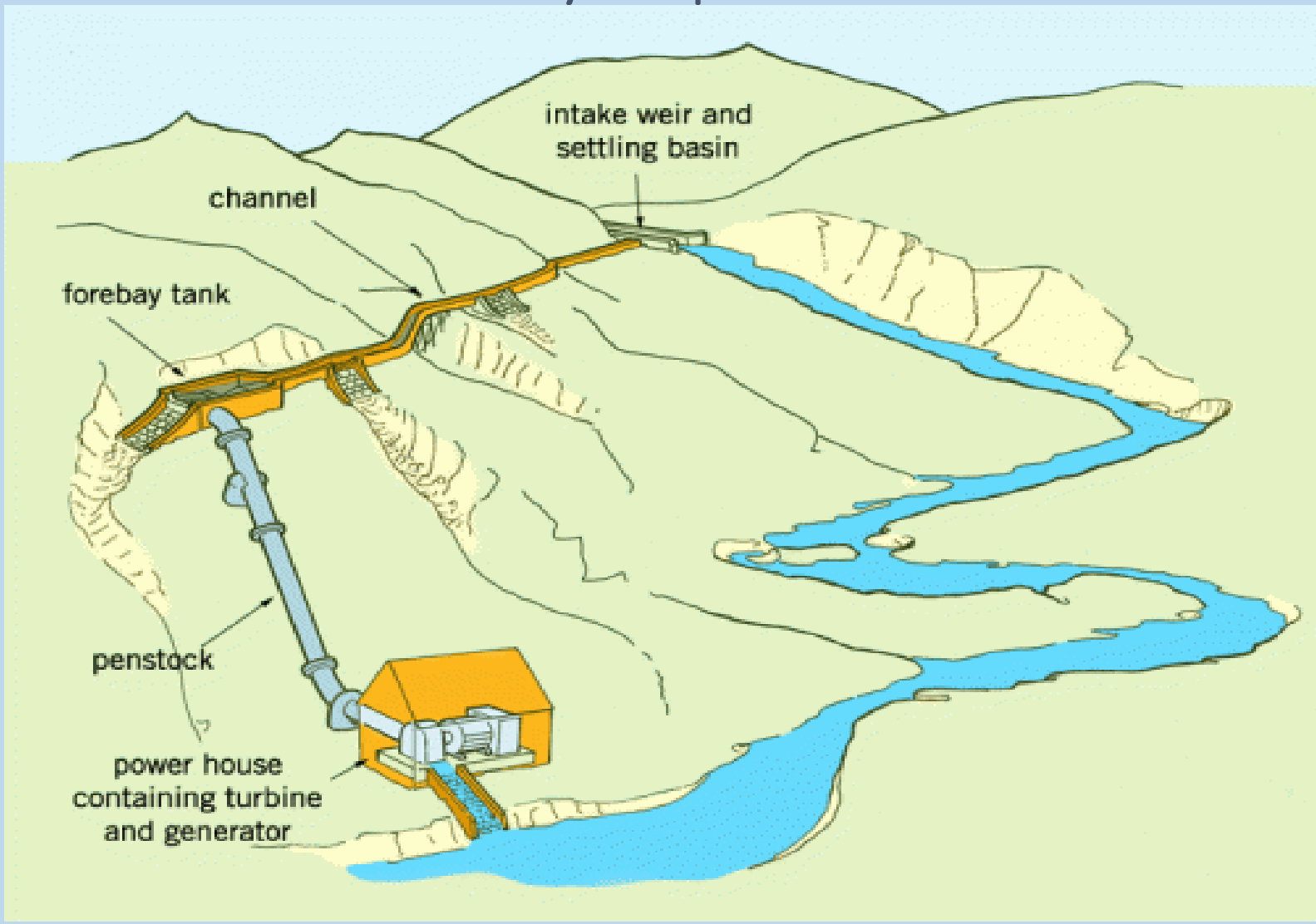
- Q, Discharge or flow drives output of the plant
- H, Head drives type of plant
- K_L, energy losses (hydraulic, mechanical, electrical)

Conventional Hydro

Conventional Hydro

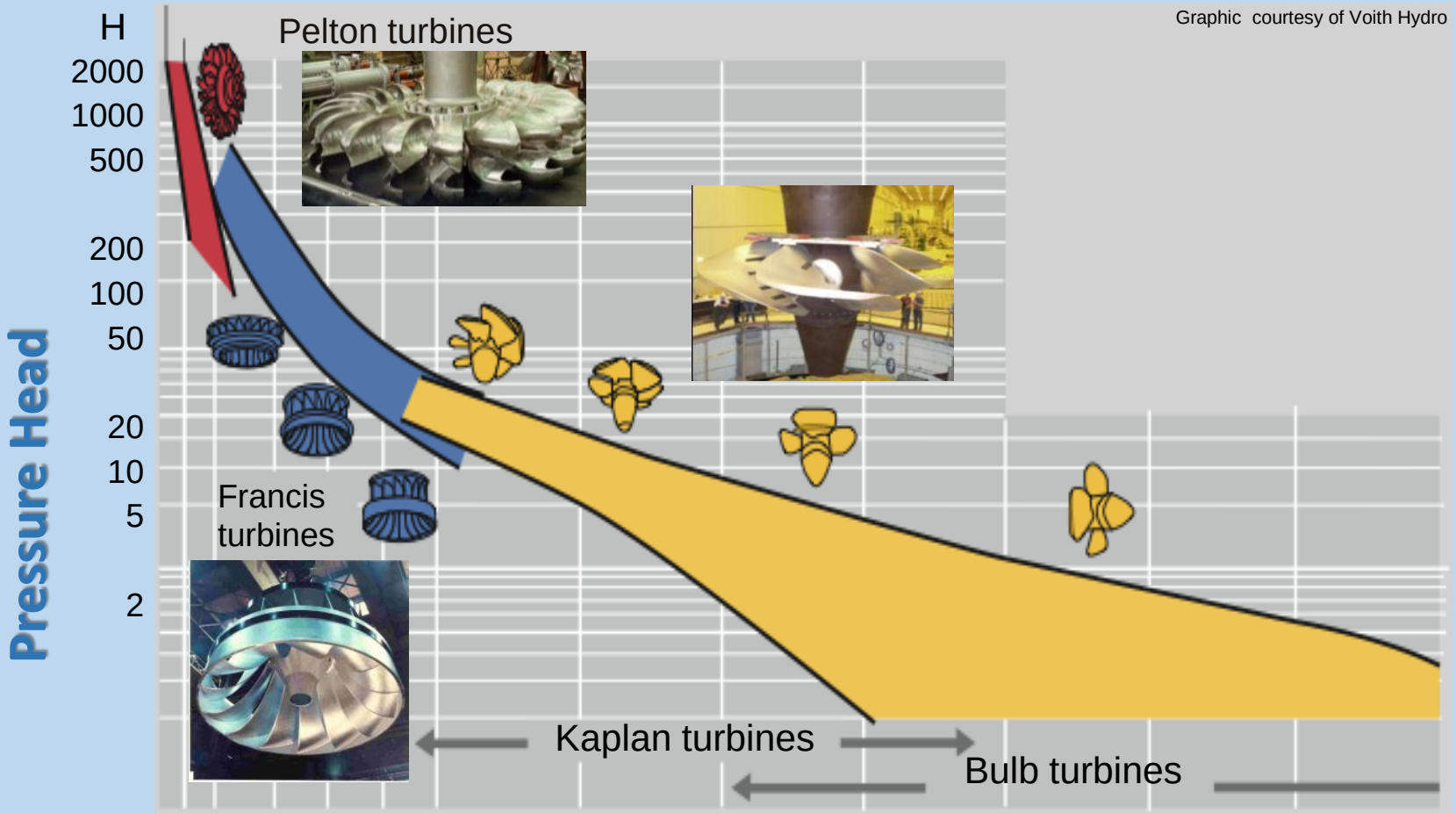
Conventional Hydro

Conventional Hydro | Run-of-the-River



turbine basics

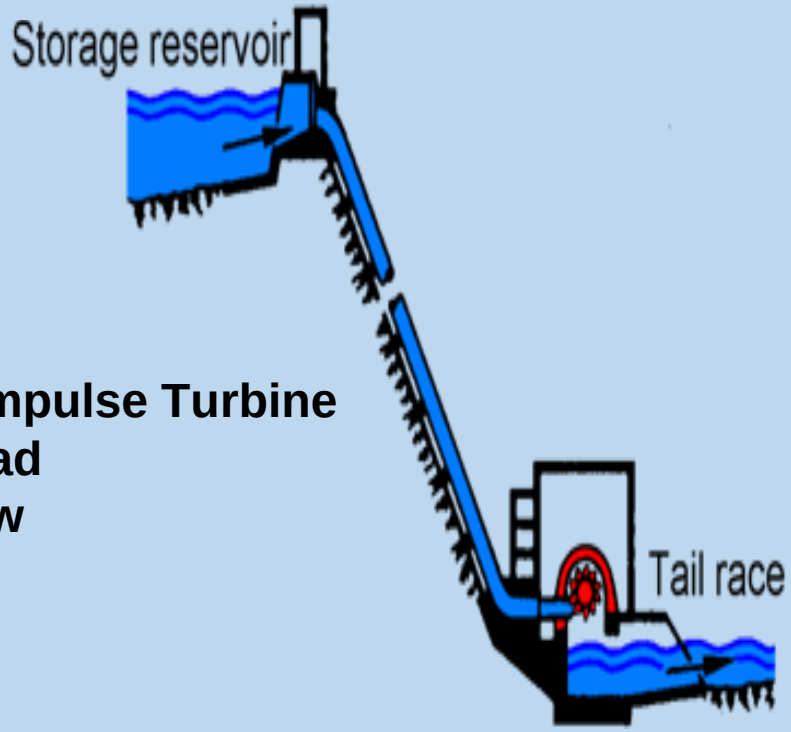
Efficiently Convert the Kinetic Energy of Head x Flow to Rotational Energy (Inertia) with the “right” Turbine



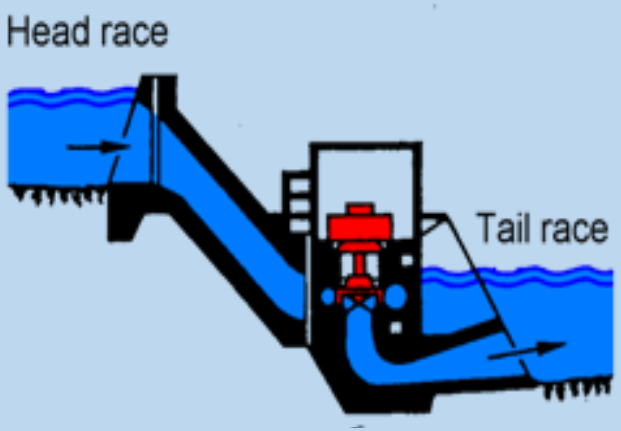
Specific Speed = function of flow and turbine characteristics

Turbine Types

Pelton or Impulse Turbine
- **High Head**
- **Low Flow**



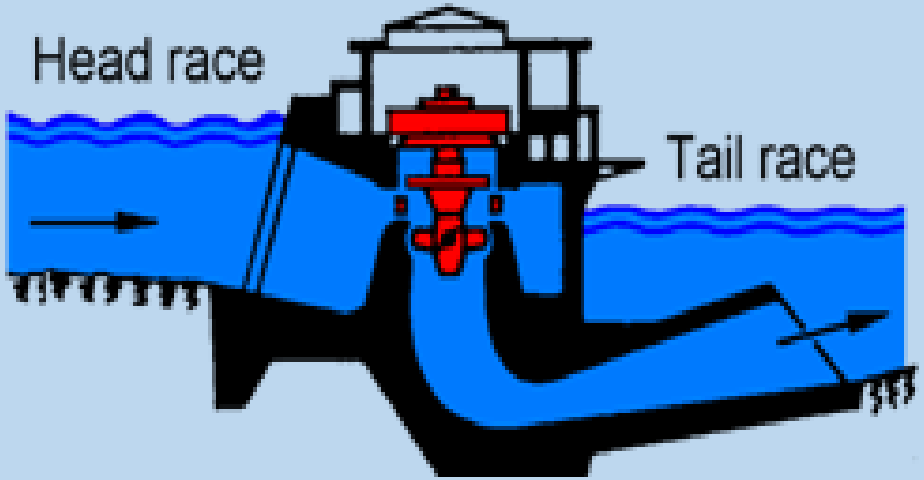
Francis Turbines
- **Mid Head**
- **Mid Flow**



Turbine Types

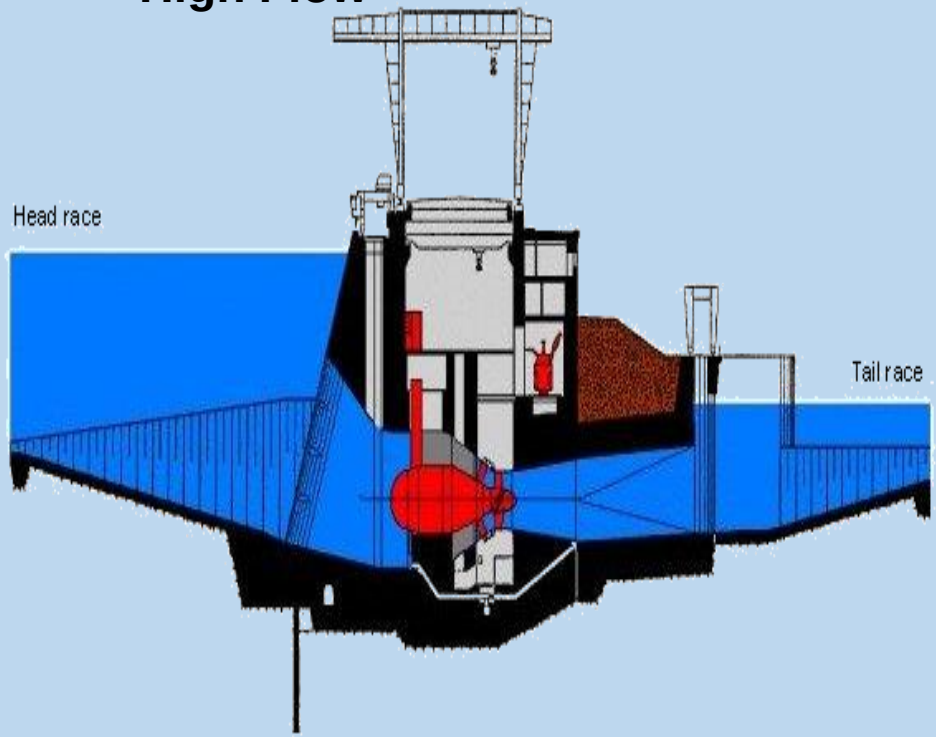
Vertical Axial Flow Turbines

- **Low Head**
- **High Flow**



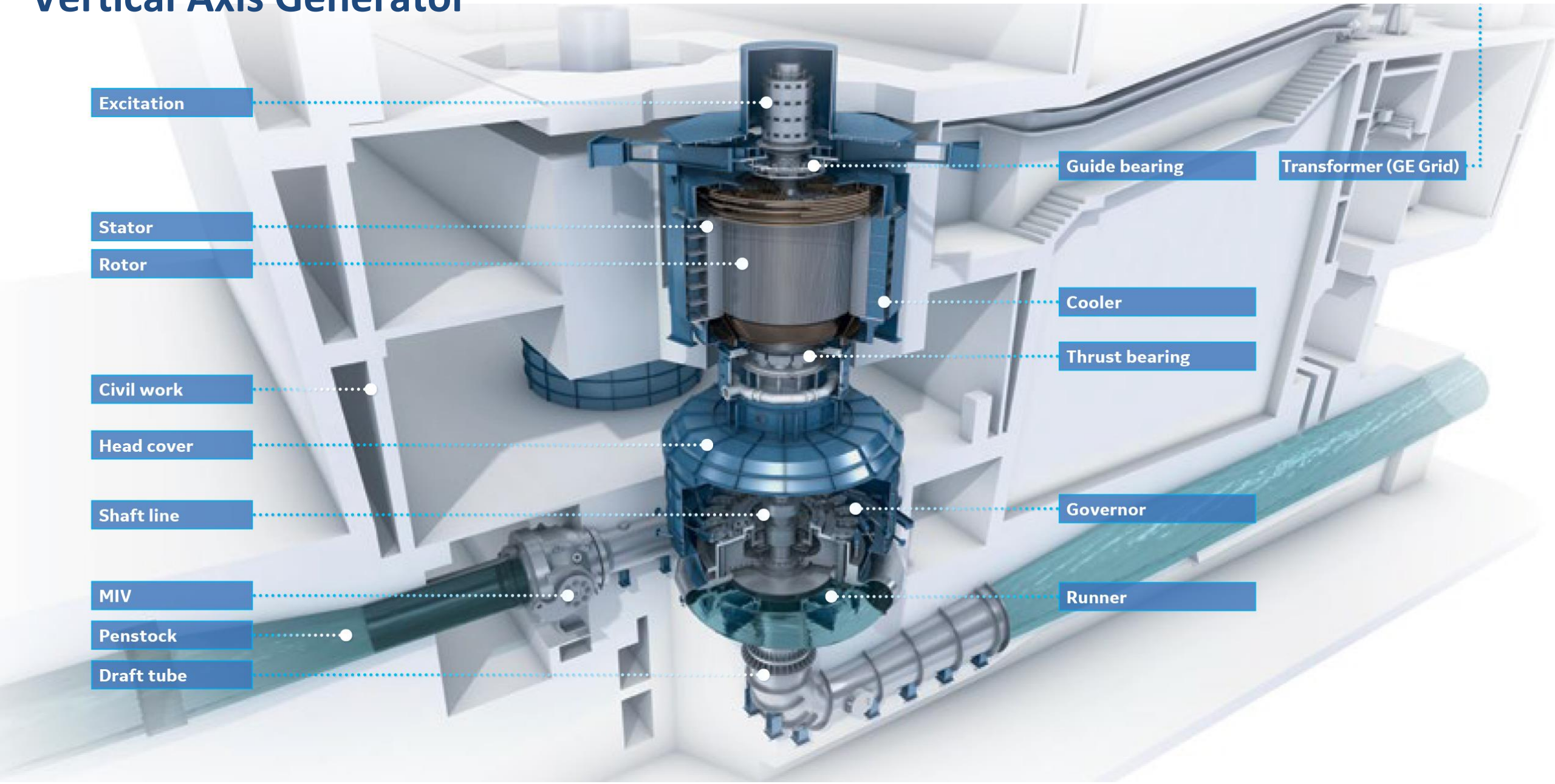
Horizontal Axial Flow Bulb Turbine

- **Low Head**
- **High Flow**

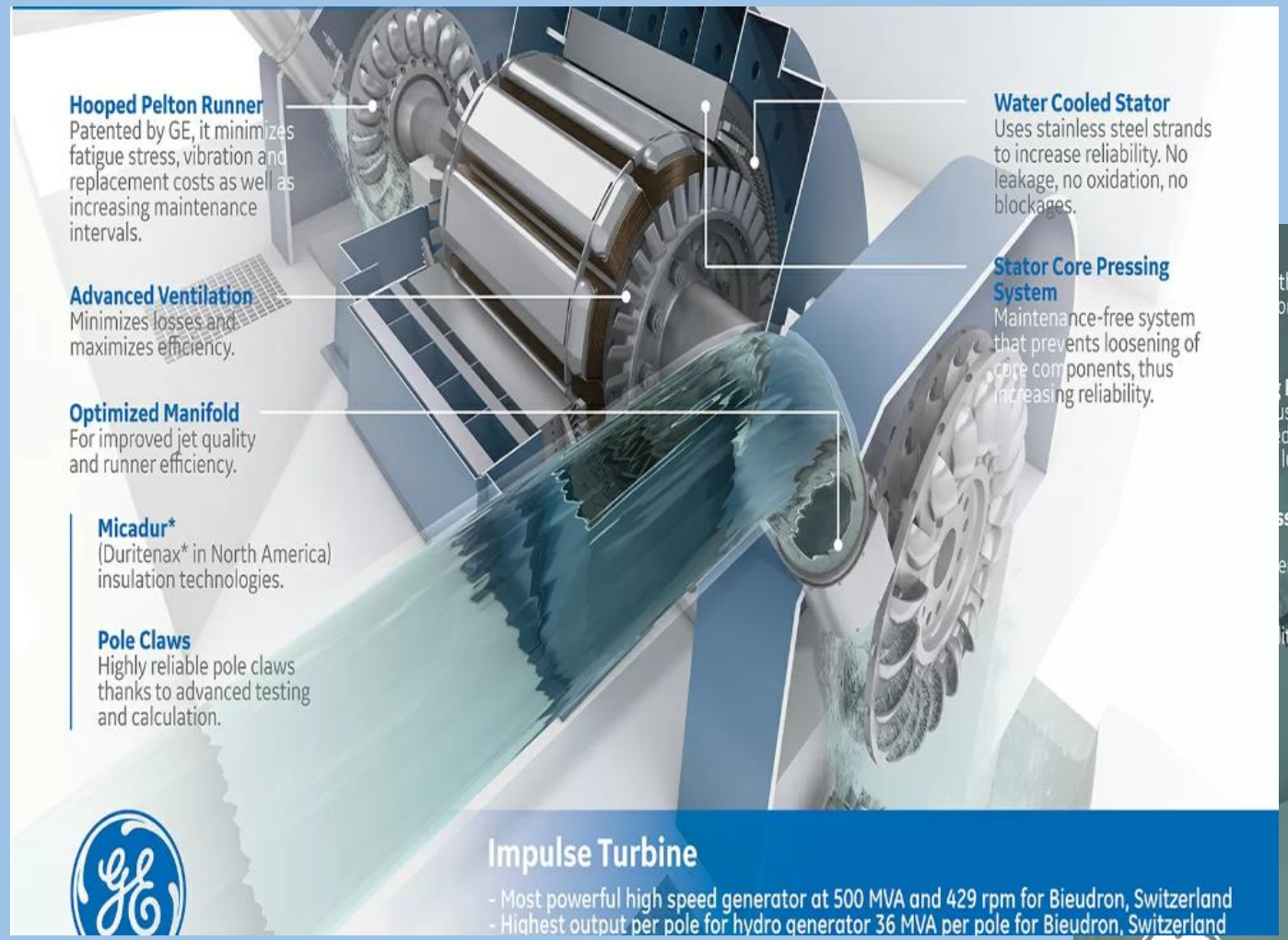


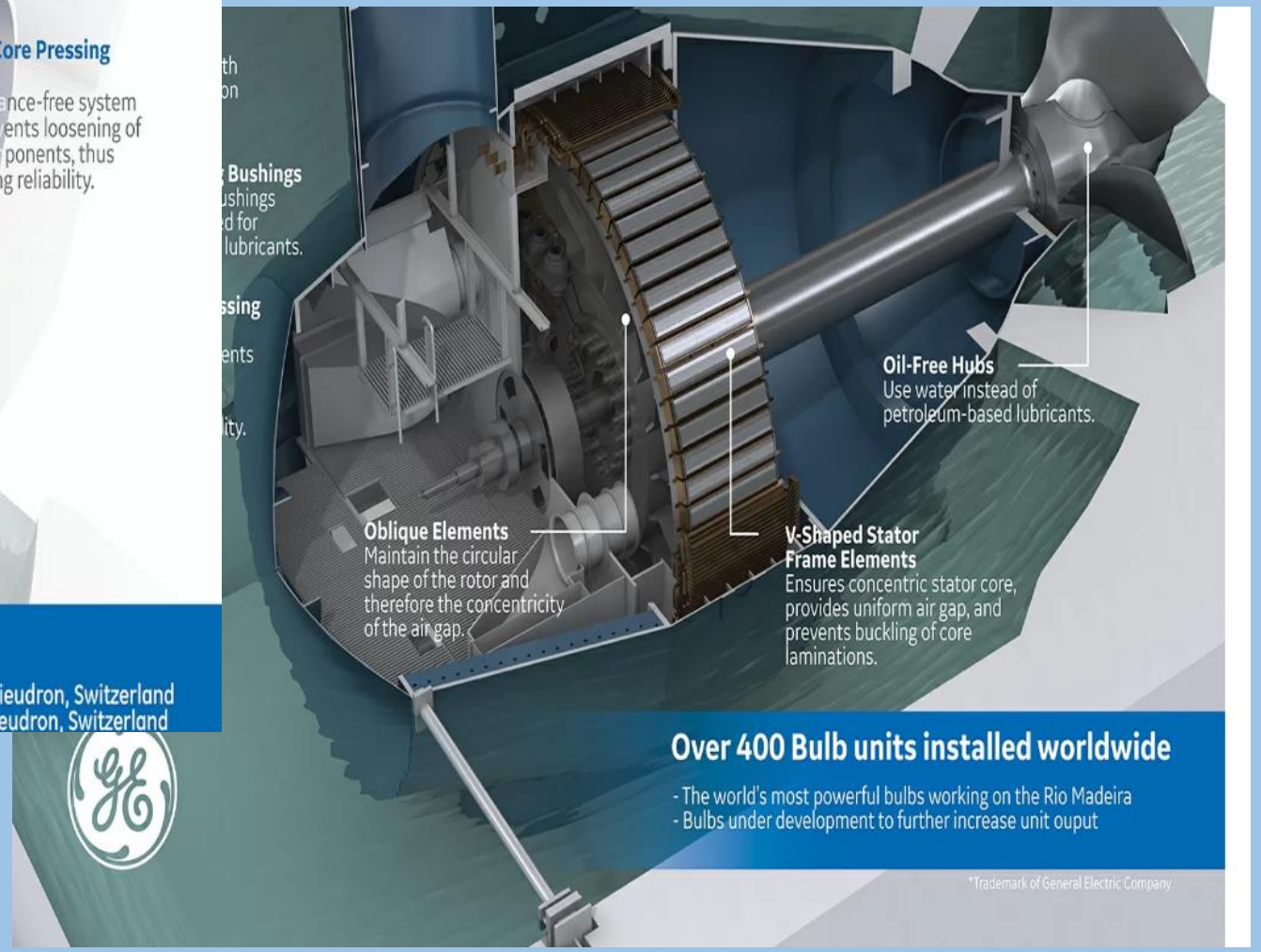
generator/motor basics

Vertical Axis Generator

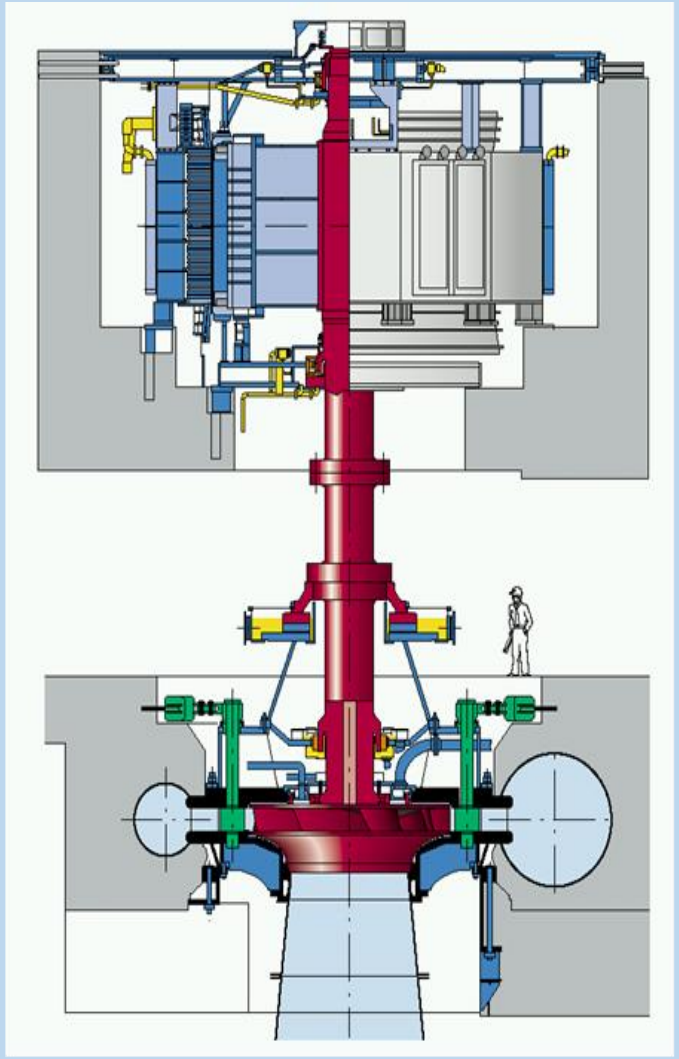


Horizontal Axis Generators



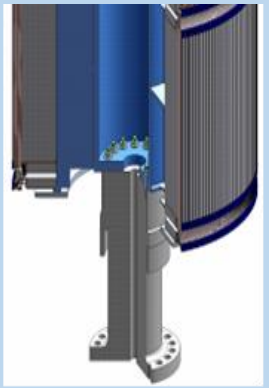


Hydro Pumped Storage
Motor-Generator/Pump-Turbine (typical configuration)



Photos & Graphics courtesy of Voith Hydro

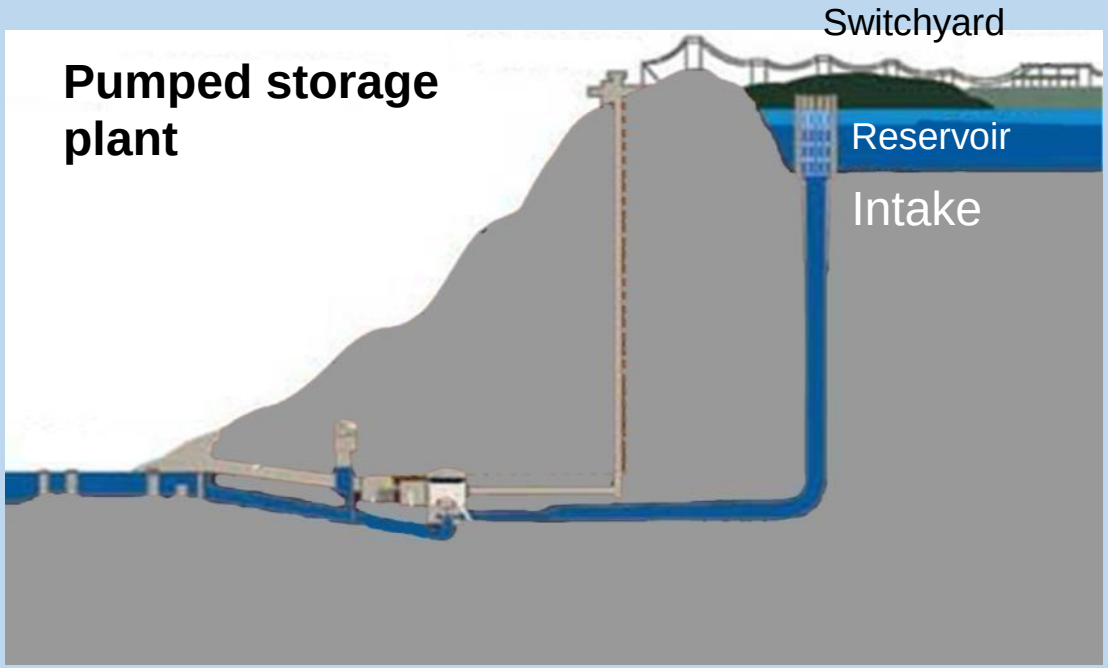
Synchronous Motor Generator Rotor



Variable Speed Motor Generator Rotor

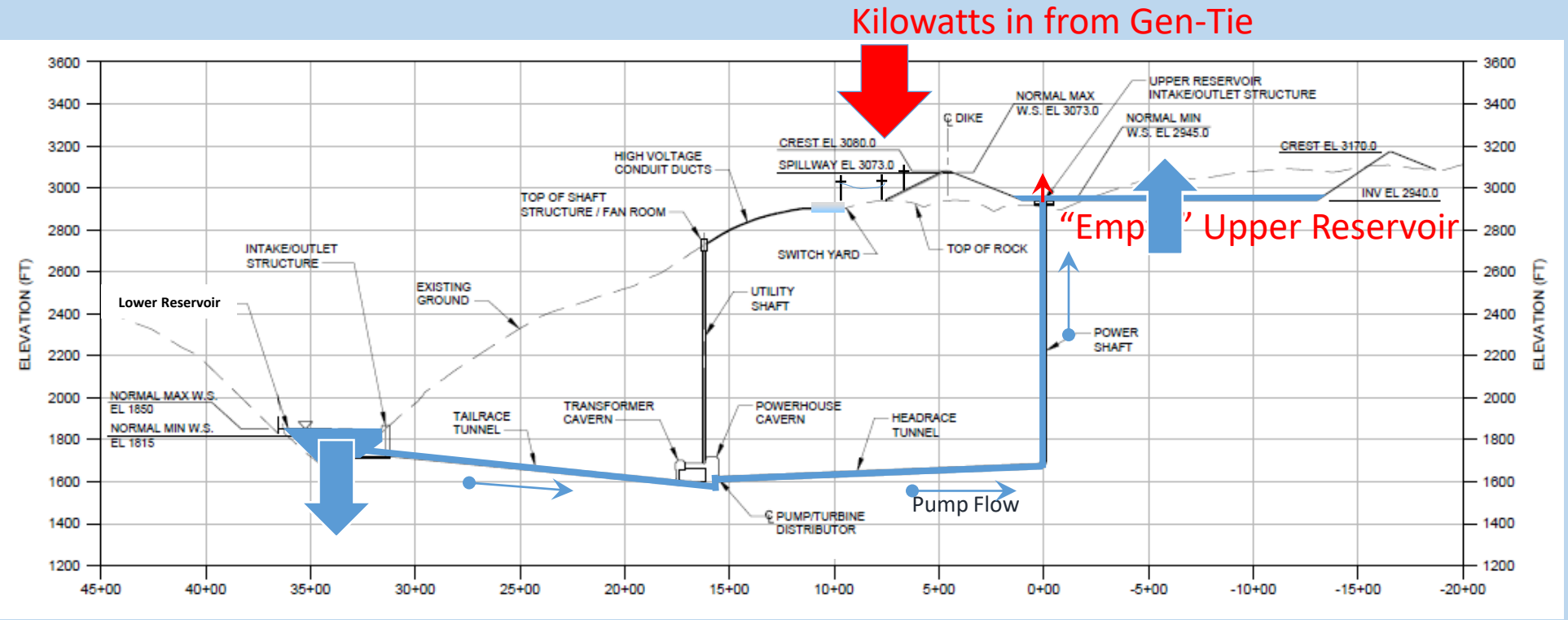
Impeller

Hydro Power for Energy Storage
Pumped Storage

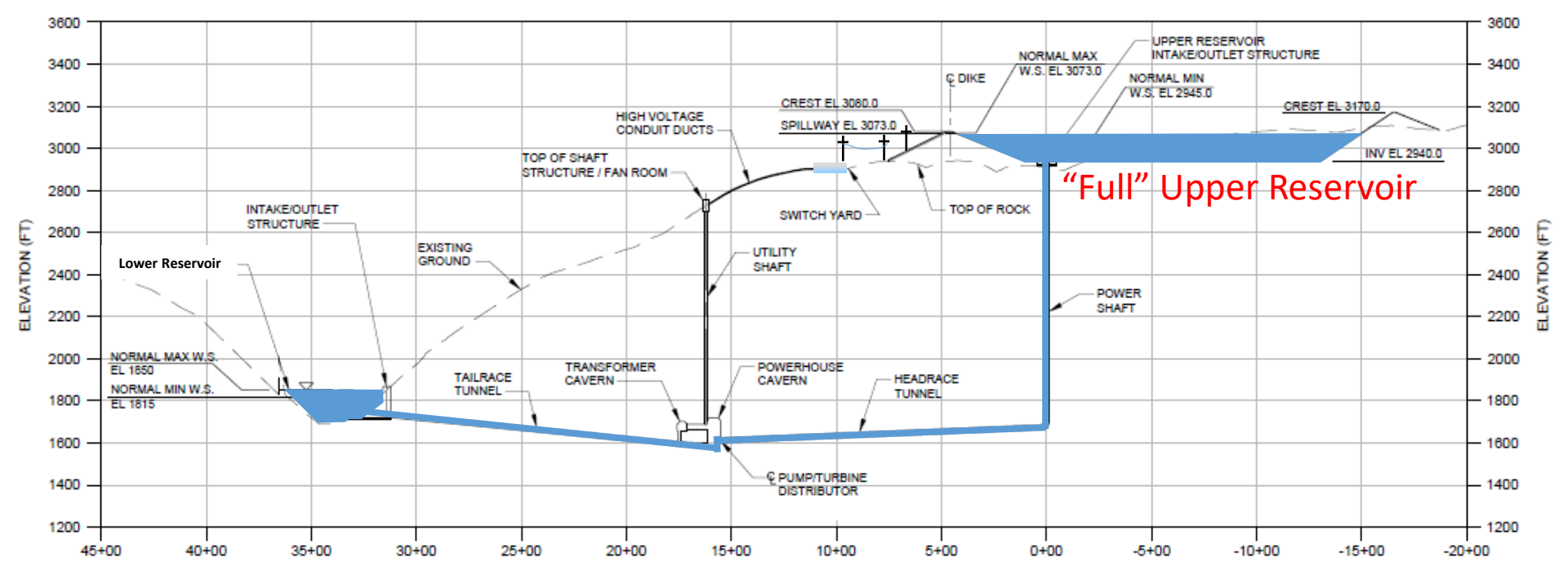


Plant & Reservoirs

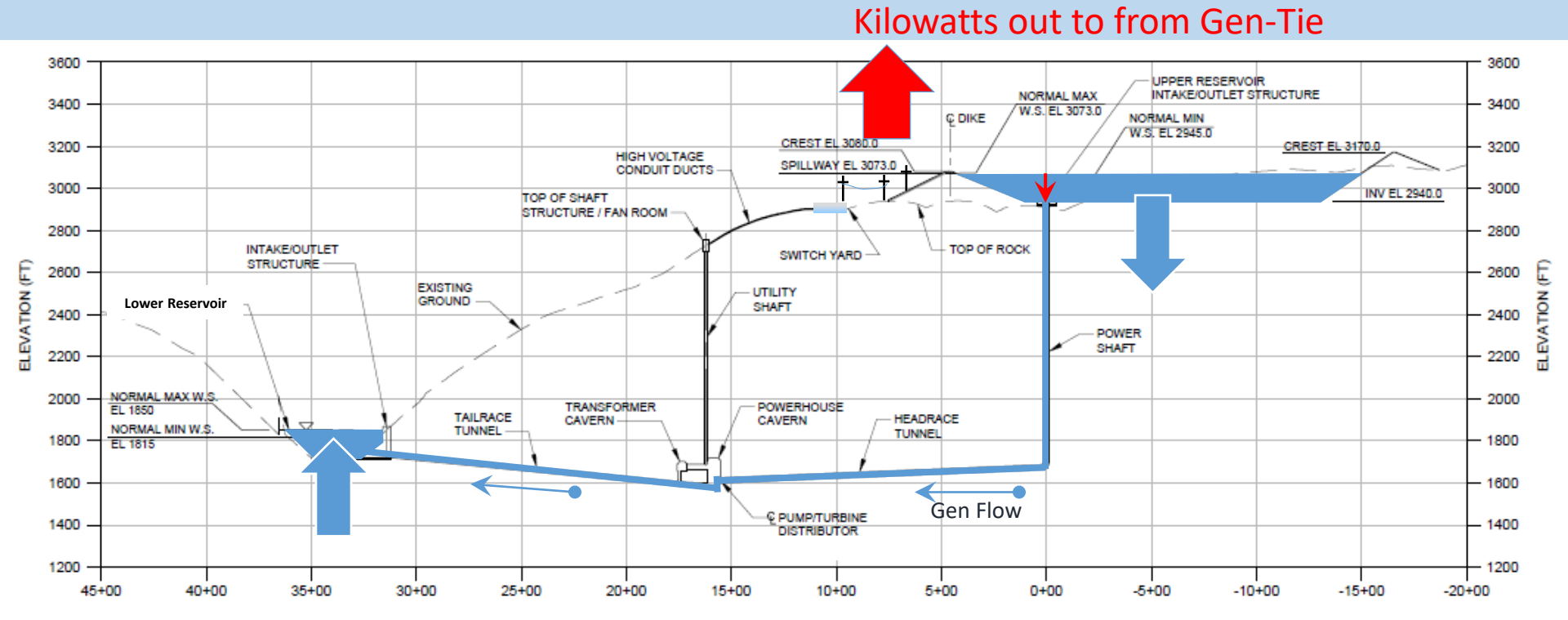
Operational Schematic | Pump Mode – Beginning of Cycle (1 of 2)



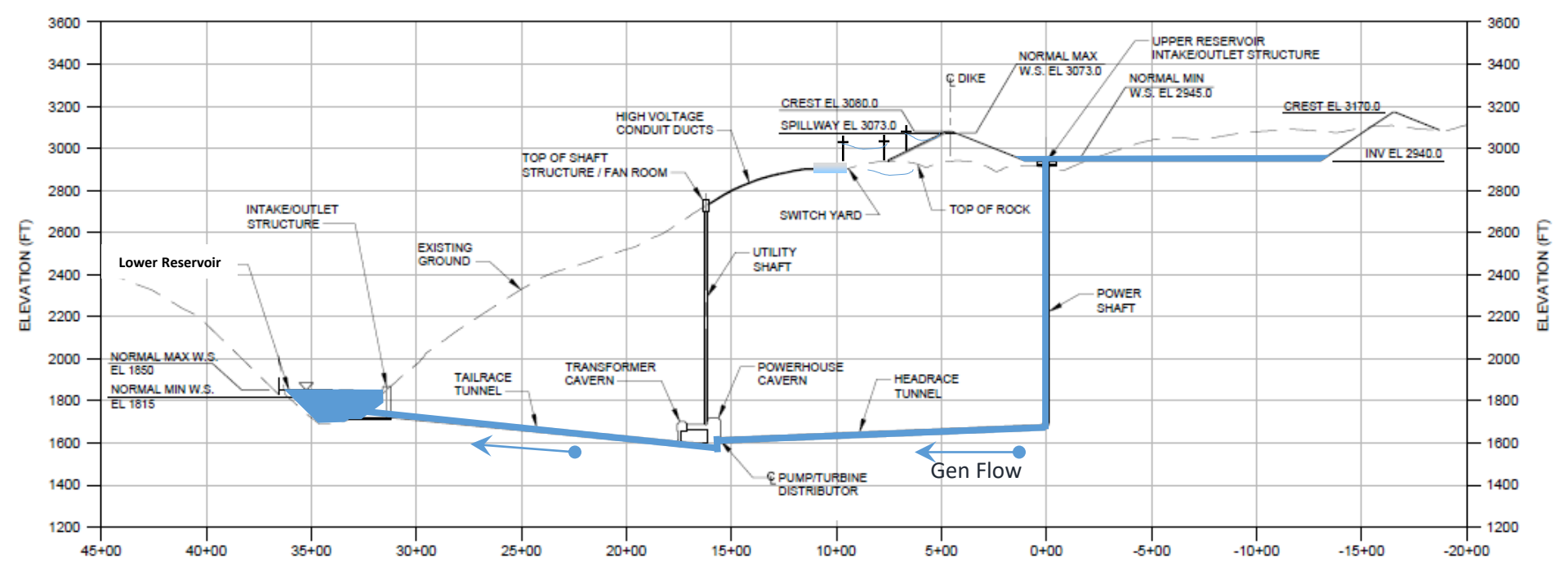
Operational Schematic | Pump Mode – End of Cycle (2 of 2)



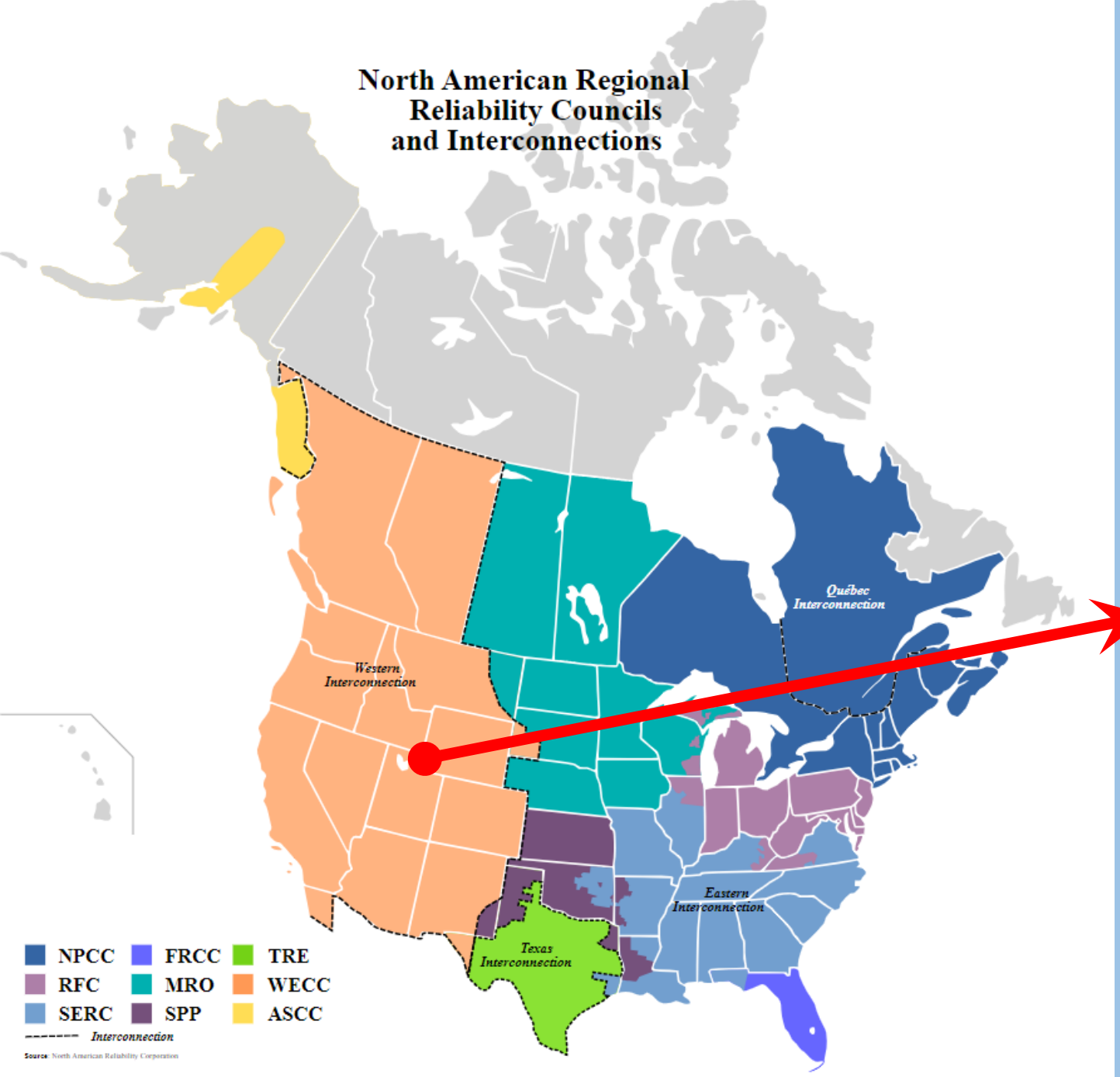
Operational Schematic | Generation Mode – Beginning of Cycle (1 of 2)

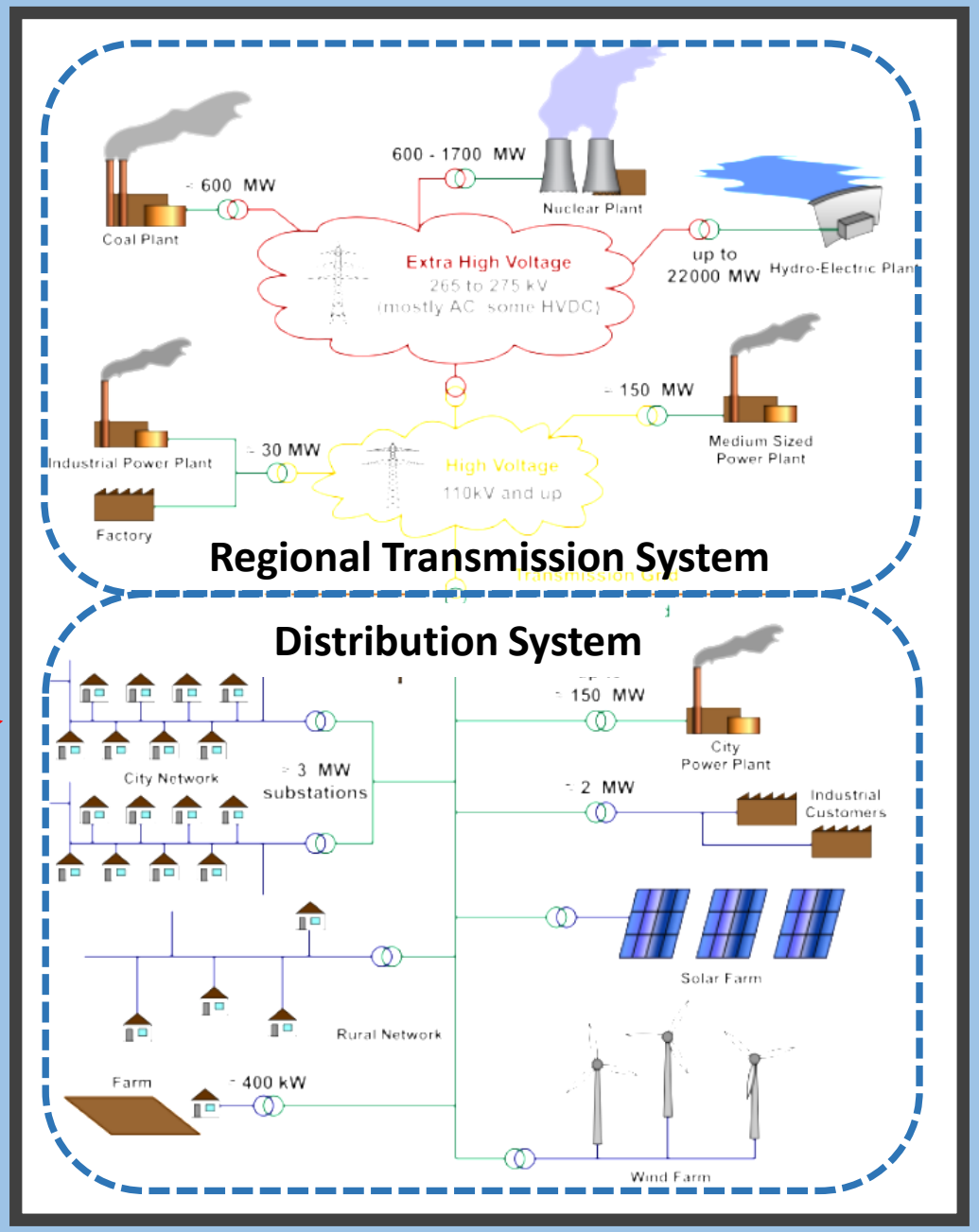


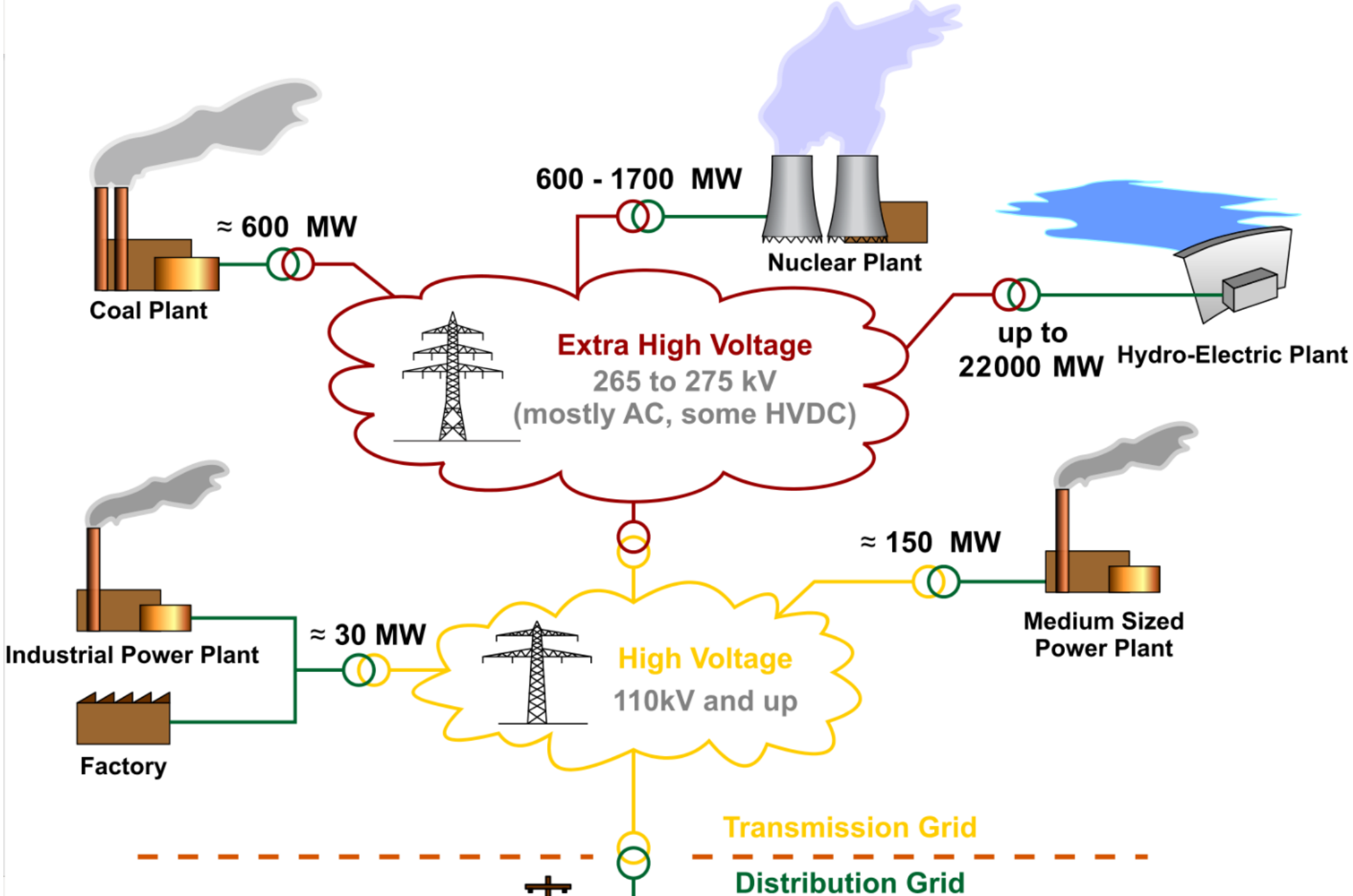
Operational Schematic | Generation Mode – End of Cycle (2 of 2)

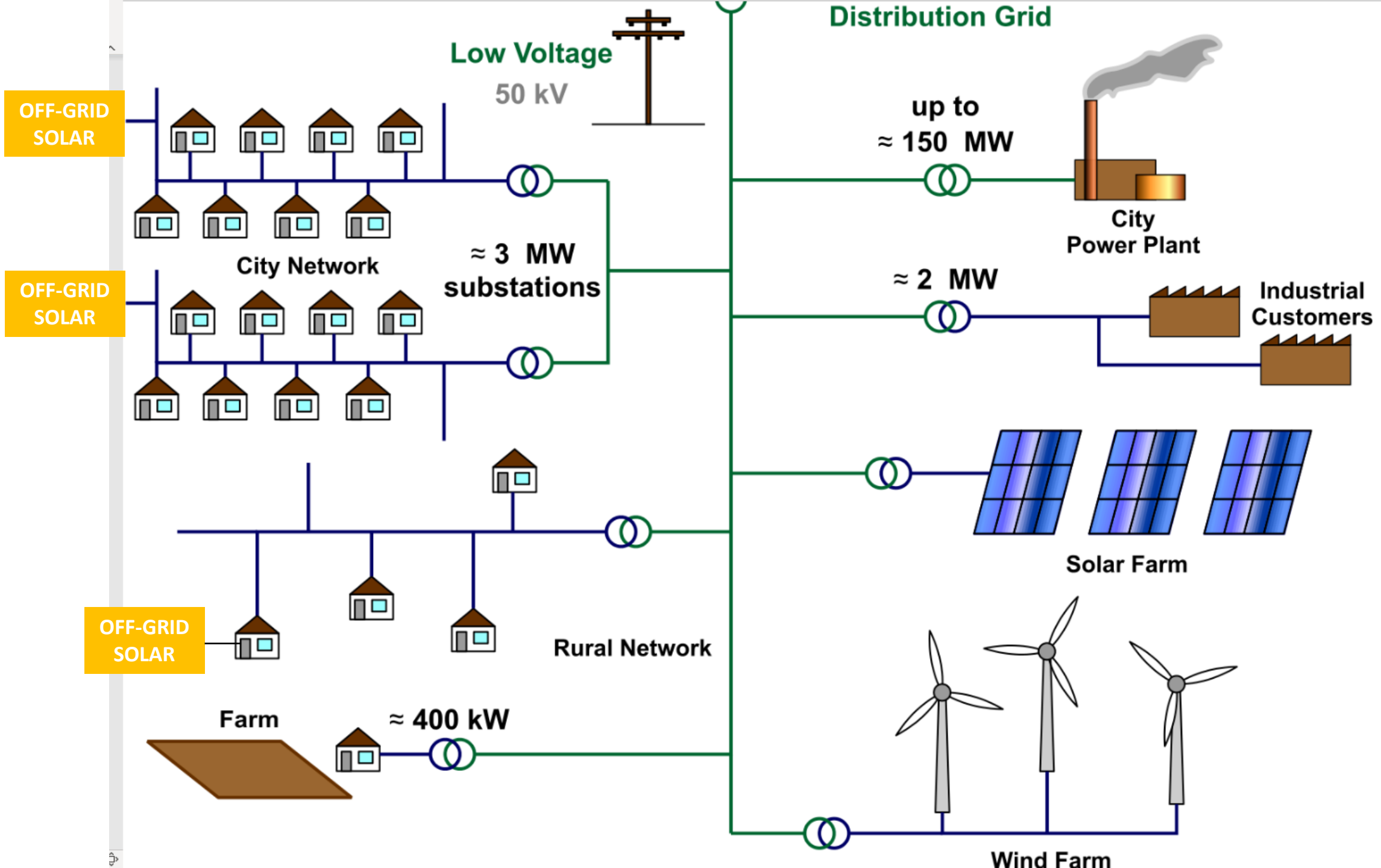


daily operations & power grid basics

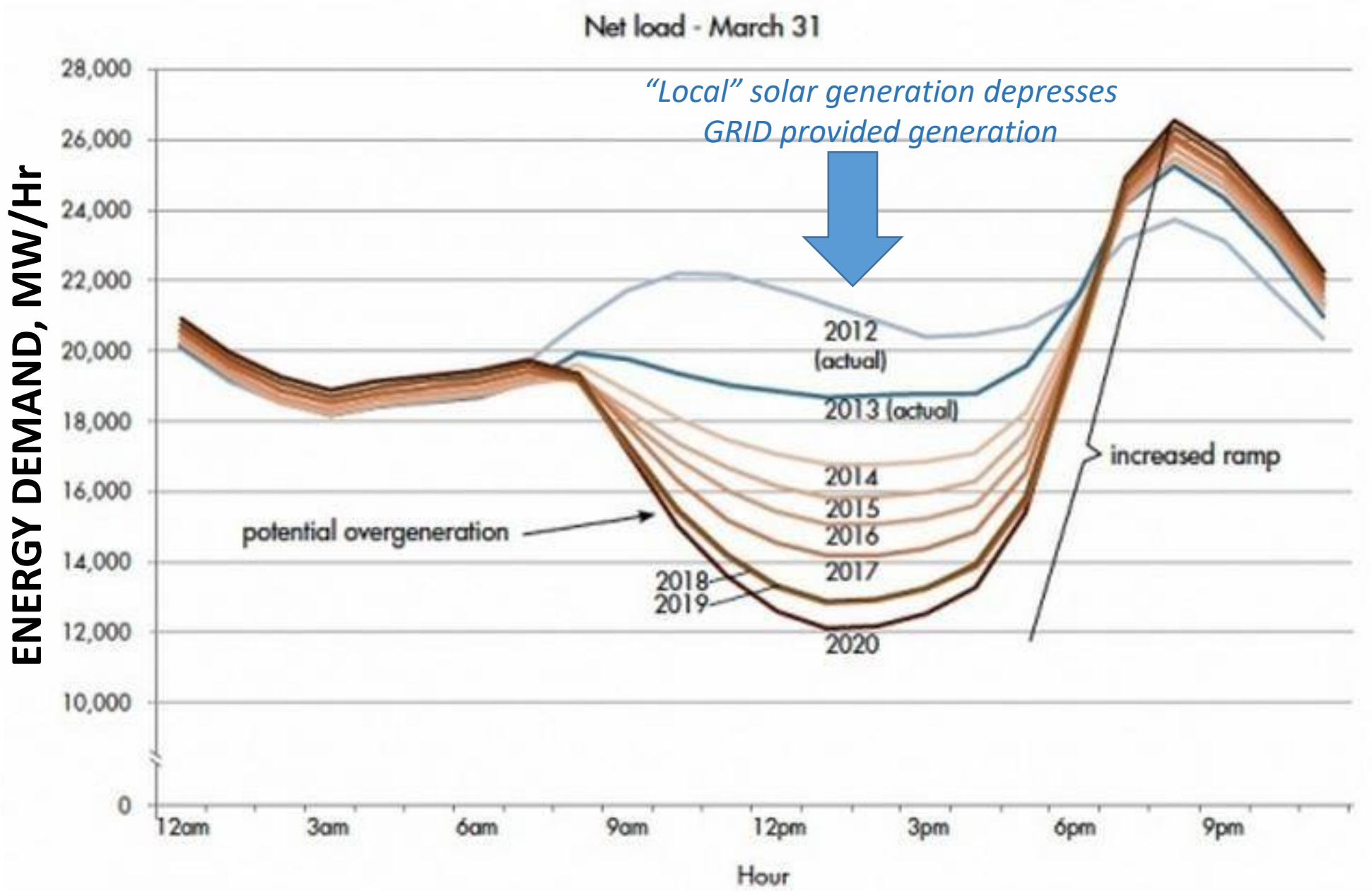

North American Regional
Reliability Councils
and Interconnections
Québec
Interconnection
Western
Interconnection
Eastern
Interconnection
Texas
Interconnection
NPCC
FRCC
TRE
RFC
MRO
WECC
SERC
SPP
ASCC
Interconnection
Source: North American Reliability Corporation


600 - 1700 MW
Nuclear Plant
600 MW
Coal Plant
Extra High Voltage
265 to 275 kV
(mostly AC, some HVDC)
up to
22000 MW
Hydro-Electric Plant
150 MW
Medium Sized
Power Plant
30 MW
Industrial Power Plant
Factory
High Voltage
110kV and up
Regional Transmission System
Distribution System
150 MW
City
Power Plant
City Network
3 MW
substations
2 MW
Industrial
Customers
Solar Farm
Rural Network
Farm
400 kW
Wind Farm
Regional Operation Grid


≈ 600 MW
Coal Plant
600 - 1700 MW
Nuclear Plant
Extra High Voltage
265 to 275 kV
(mostly AC, some HVDC)
up to
22000 MW
Hydro-Electric Plant
≈ 150 MW
Medium Sized
Power Plant
Industrial Power Plant
≈ 30 MW
Factory
High Voltage
110kV and up
Transmission Grid
Distribution Grid

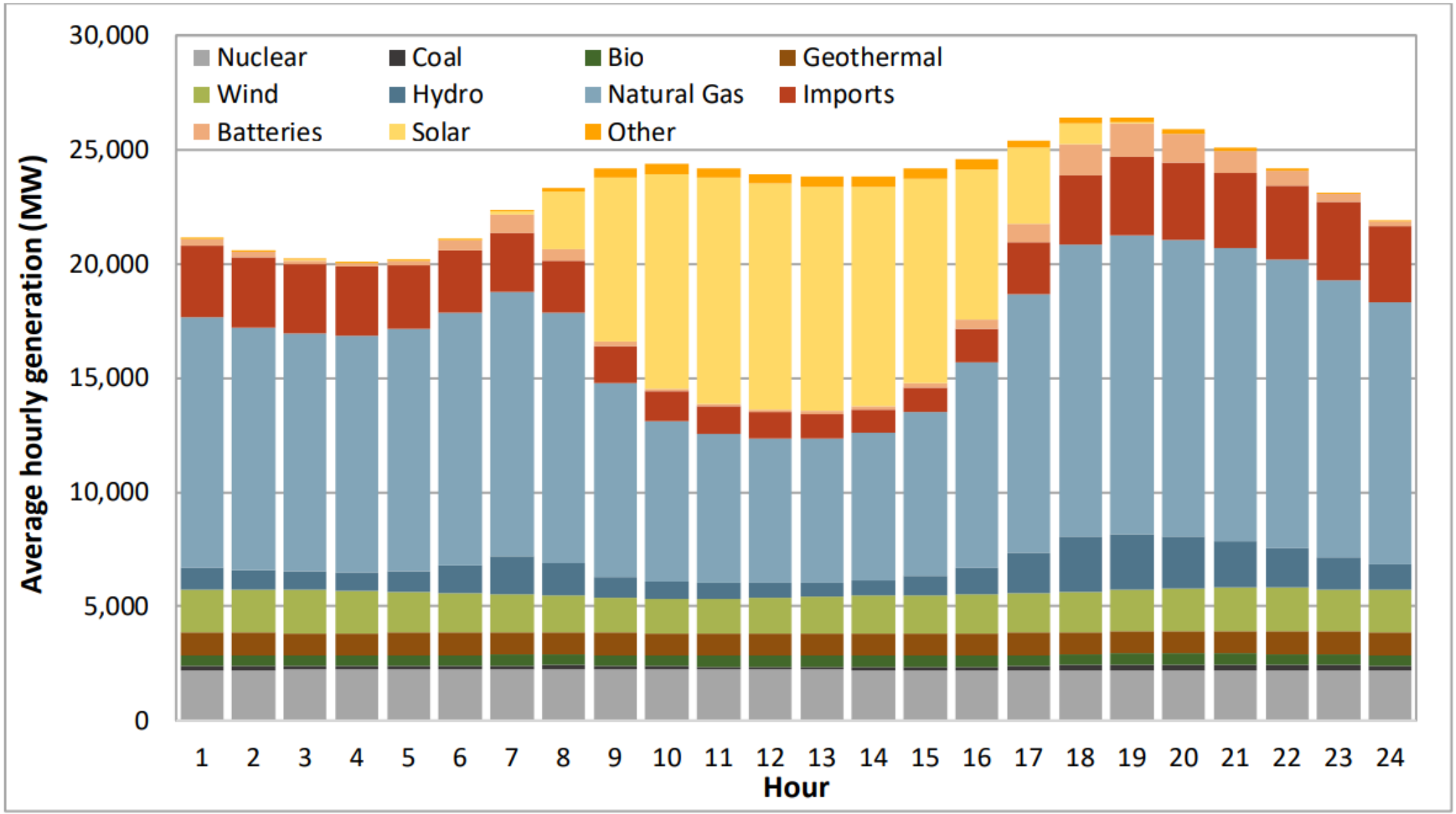

Distribution Grid
Low Voltage
50 kV
OFF-GRID SOLAR
OFF-GRID SOLAR
OFF-GRID SOLAR
City Network
≈ 3 MW substations
up to ≈ 150 MW
City Power Plant
≈ 2 MW
Industrial Customers
Solar Farm
Rural Network
Farm
≈ 400 kW
Wind Farm

The Duck Curve: What is it and what does it mean?

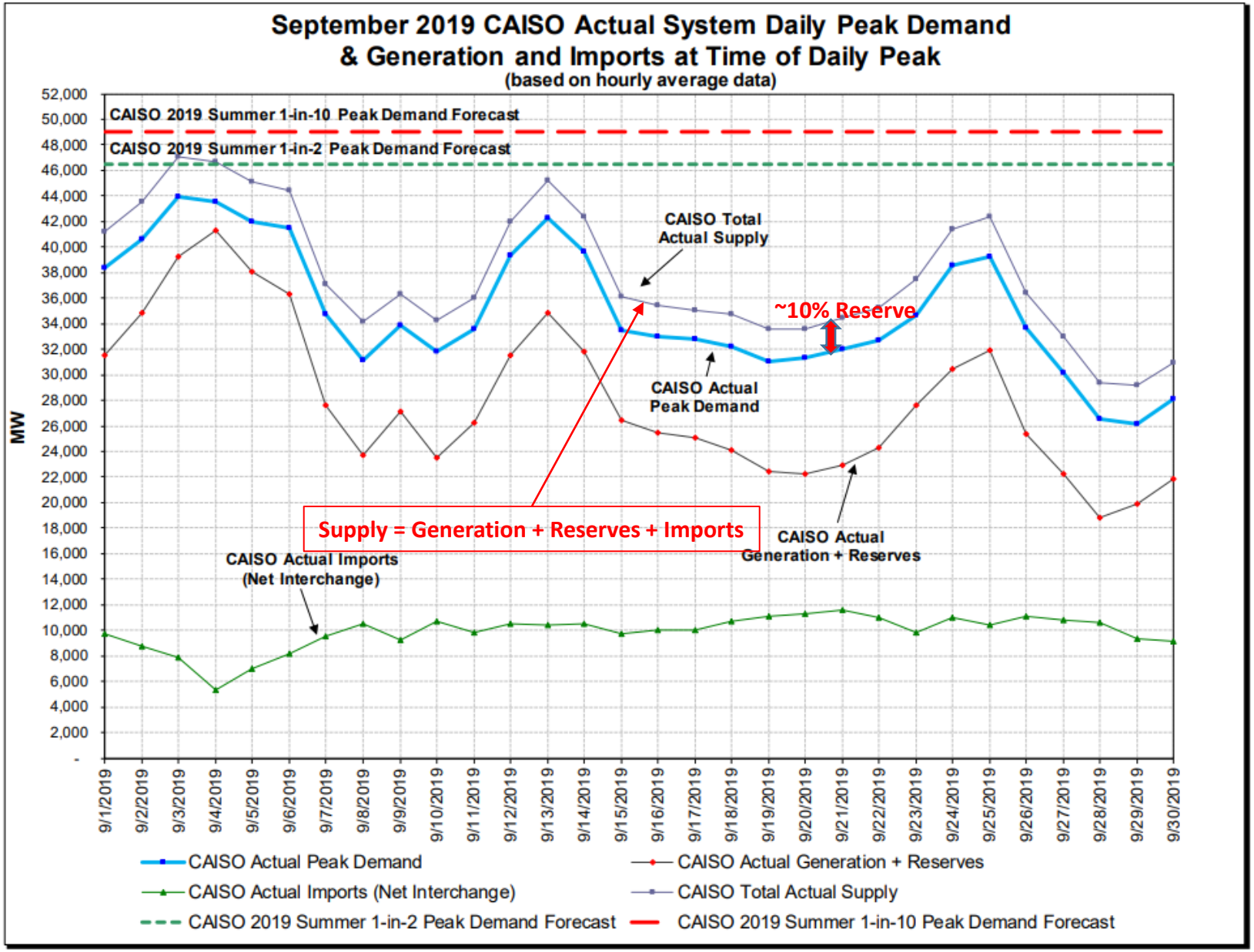


Energy Alabama. 2017.05.29.

Figure 1.4 Average hourly generation by fuel type (Q4 2022)



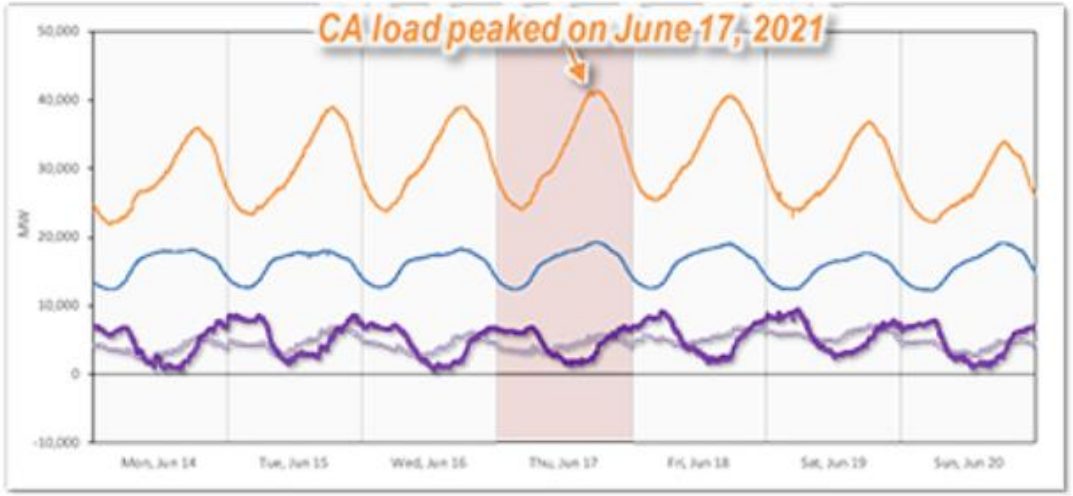
Appendix A: 2019 Summer Supply and Demand Summary Graphs



"A tale of two heat waves"

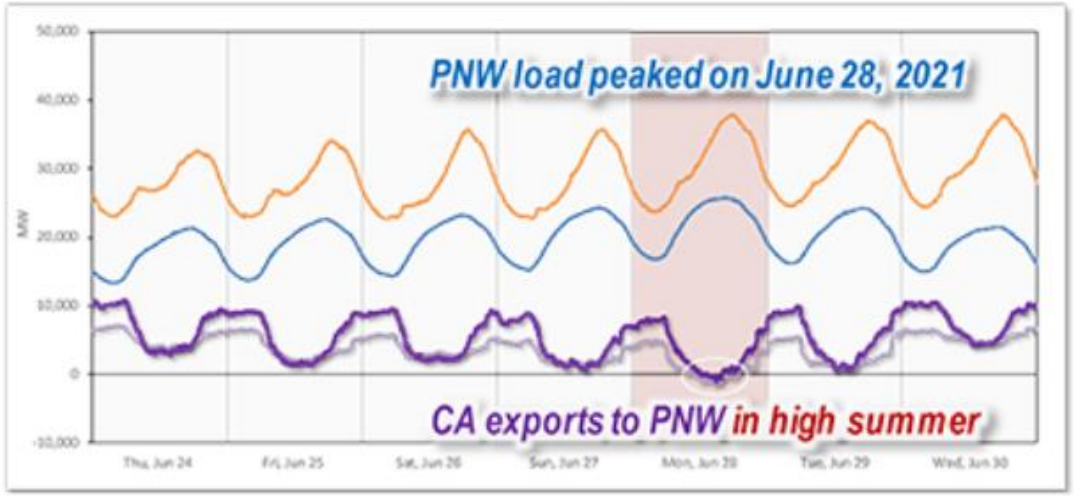
Heat wave in California (CA)

Mid-June 2021



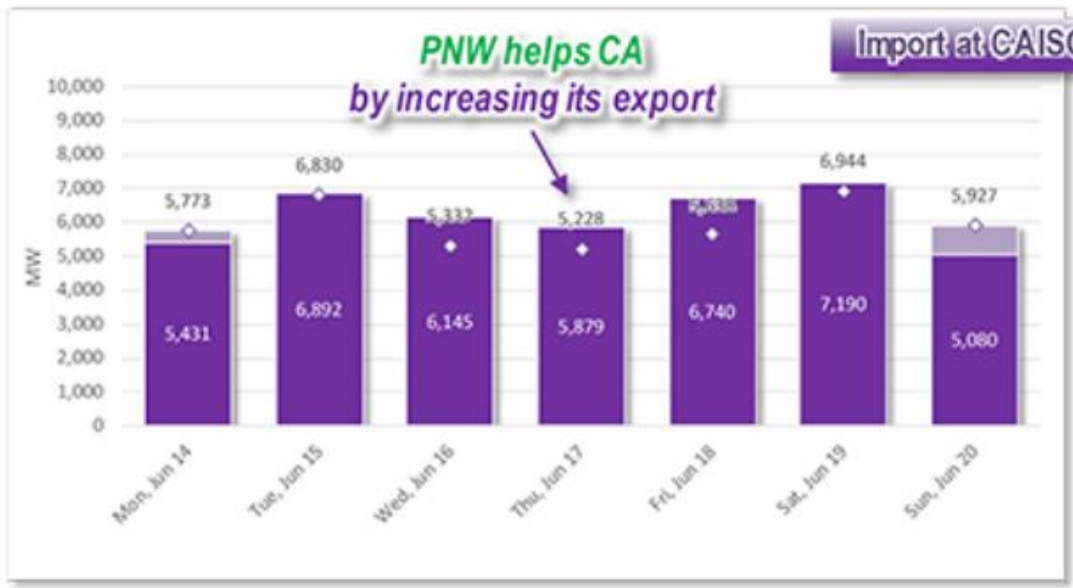
Heat wave in Pacific Northwest (PNW)

End-June 2021



CAISO load • PNW load of WEIM entities • CAISO total import • CA import from PNW via COI and PDCI

Acronyms of transmission paths: COI = California-Oregon Intertie, PDCI = Pacific DC Intertie



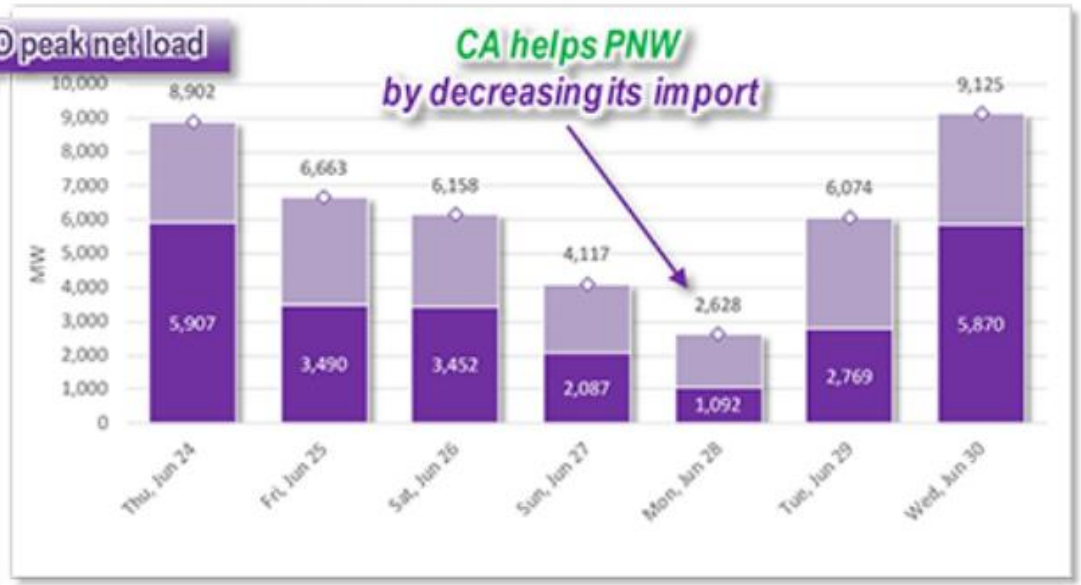
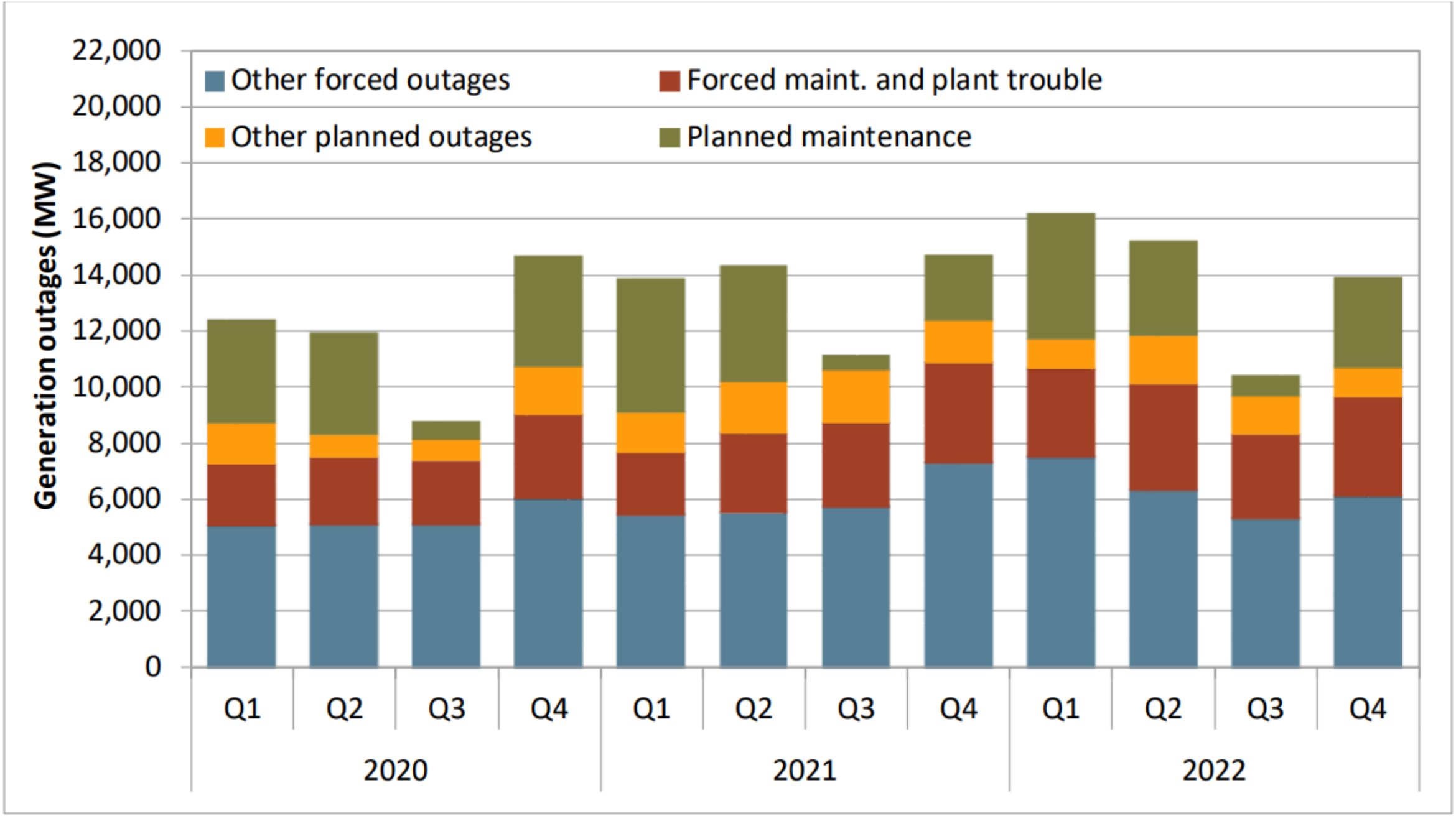


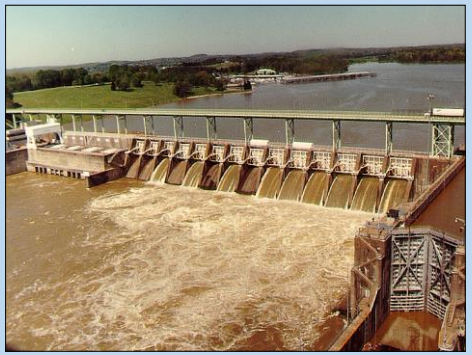
Figure 1.7 Quarterly average of maximum daily generation outages by type – peak hours



stakeholder basics

Multiple Uses / Multiple Benefits

Dams and Reservoirs provide other attributes than power



Flood / Storm Control

Navigation

Water Supply & Drought Mitigation

Irrigation

Recreation

Environmental Considerations

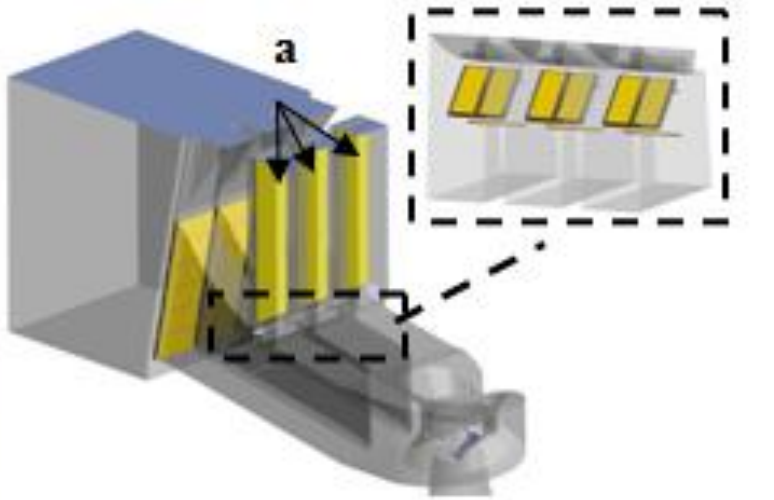
- **Fish Passage**
- **Instream Flow Releases**
- **Water Quality -- Dissolved Oxygen, Temperature, Turbidity**

Fish Passage

- Hydroelectric dams can impede migrating fish.
- Several methods are used to divert fish around the turbines.

Spilling

Surface Water Collector



Fish Diversion Screens

Key Factors Influencing Survival

Reducing Fish Entrainment

- Escapable approach velocities
- Inlets positioned in lower fish density zones
- Use fish-friendly deterrents and screening systems

Reducing Fish Injuries

- Consider fish size when designing turbine
- Require smooth concrete and steel surfaces
- Improving water quality (DO)

Dissolved Oxygen Enhancement

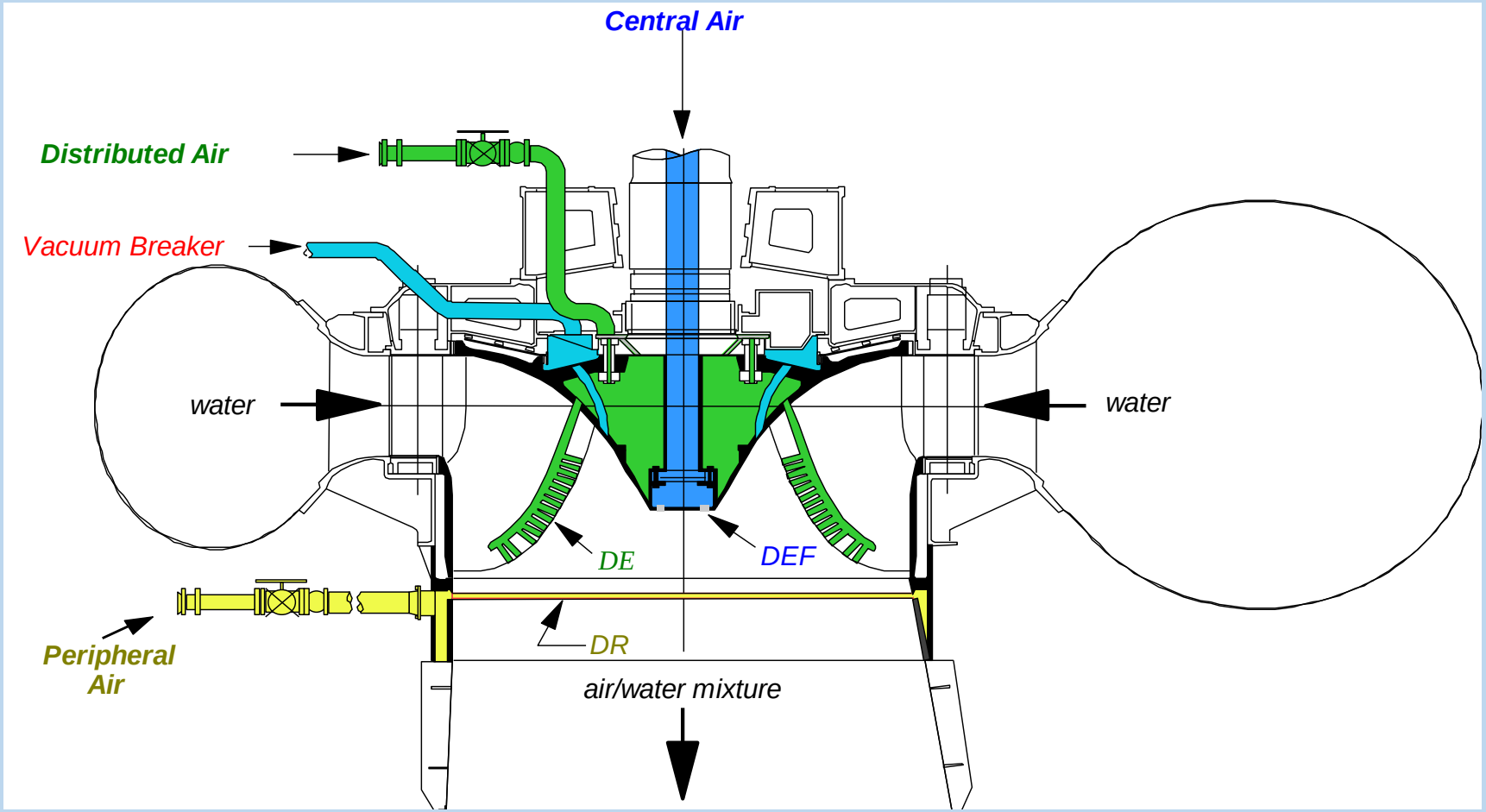
Aeration improves water quality by increasing DO levels

air introduced into the water passing through turbine

two-phase mixture causes oxygen to pass from higher to lower concentration (gas to liquid)

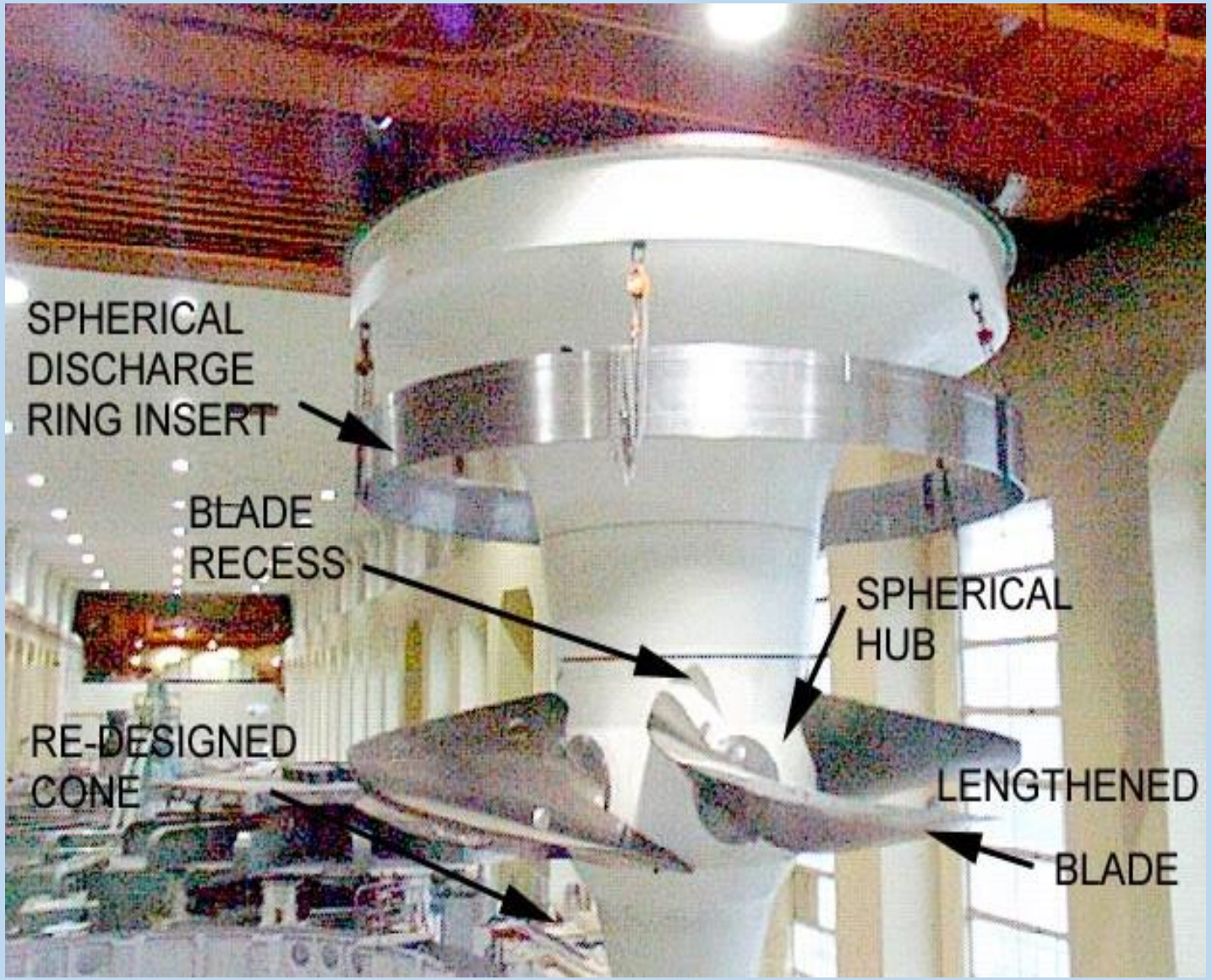
Restore tailrace DO levels to 4-6 mg/liter

Aeration Techniques Within Turbine



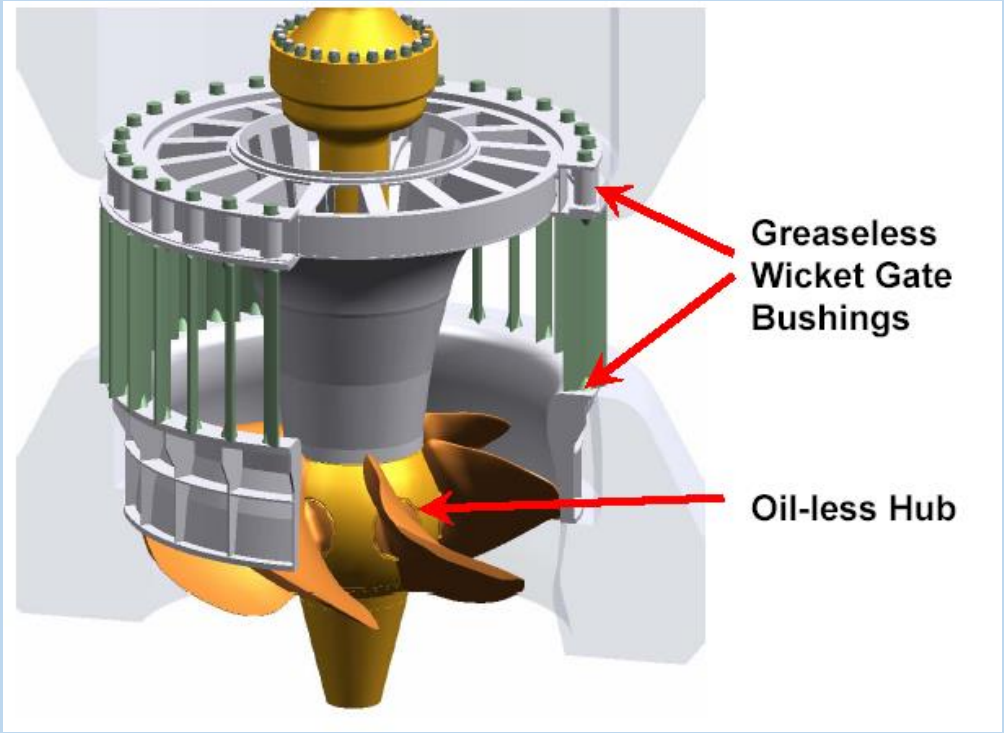
Advanced Fish Friendly Turbine

Conventional Design

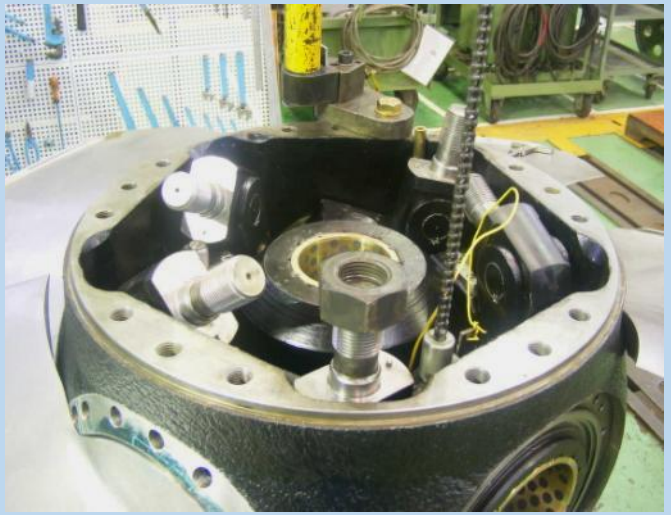


Oil Free Turbines

Oil-less and greaseless designs can be combined with Fish Friendly Kaplan turbines to reduce water contamination.

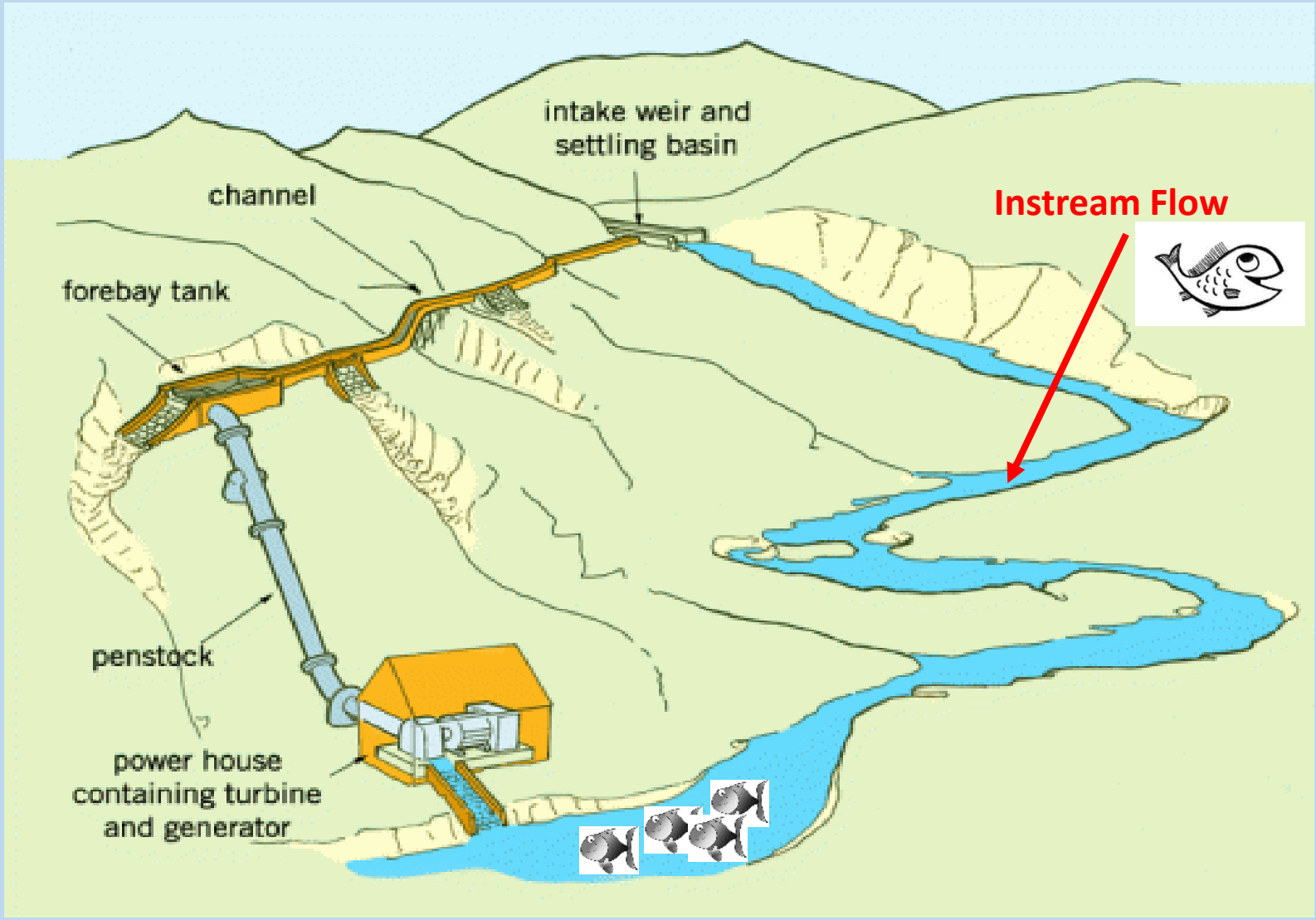


Oil-less water filled Kaplan hub



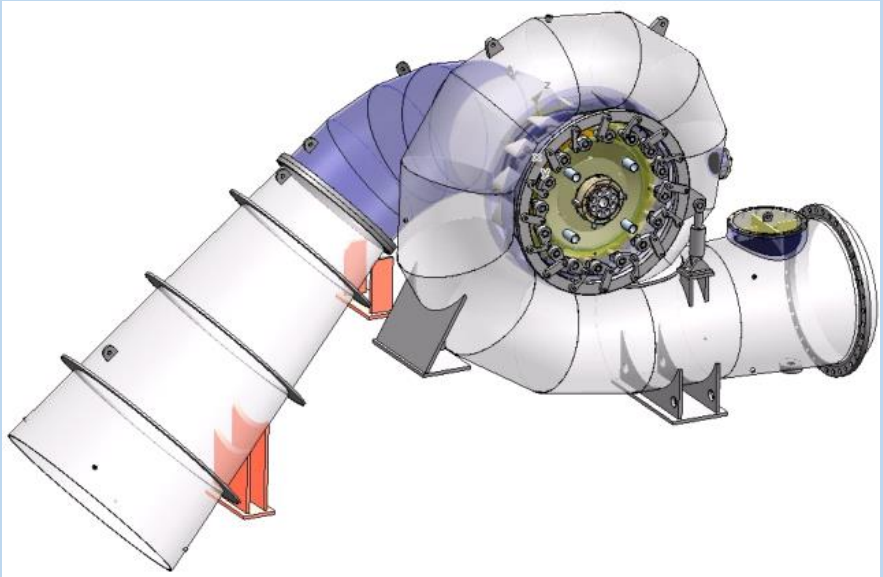
Photos& Graphics courtesy of Voith Hydro

Instream Flow



Minimum Stream Flow

- Some multi unit plants have had one unit redesigned to pass much smaller flows.
- Others utilize small standardized units for cost effective solutions



Photos& Graphics courtesy of Voith Hydro

emerging opportunities

Developing Hydropower Technologies

Ocean / Tidal

- Wave
- Current
- Thermal

In Stream

- Current

Developing Hydropower Technologies

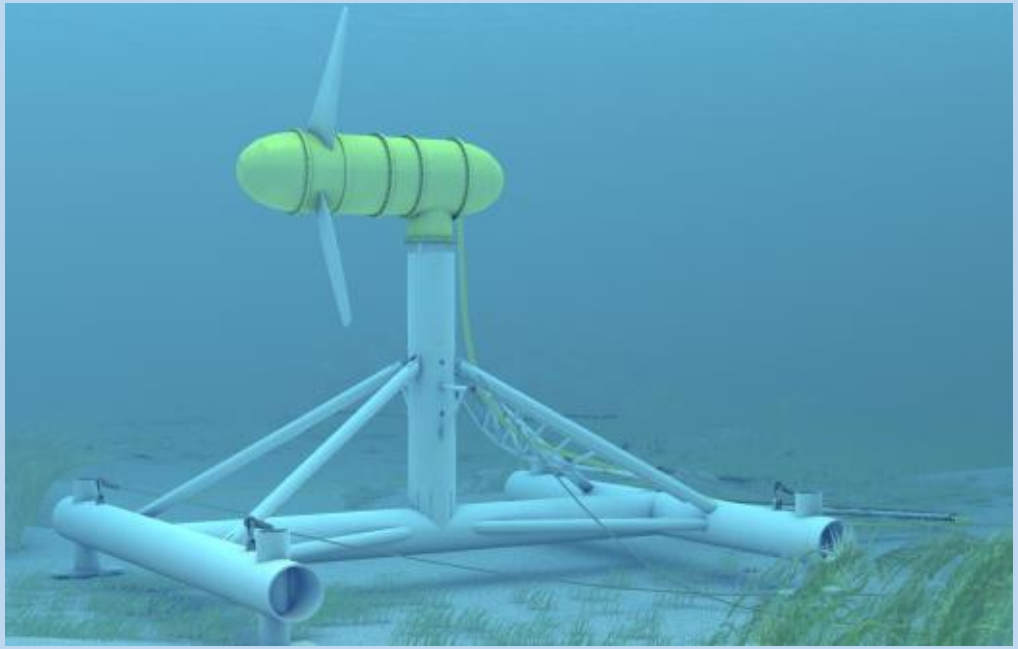
Tidal Dam

- Sea water flows into (and out of) a natural basin
- Dam creates head
- Classical hydro technology

Developing Hydropower Technologies

Tidal Current

- Kinetic energy of the periodically returning tides is harvested
- Tidal current plant is a dam-free free-flow hydro power plant

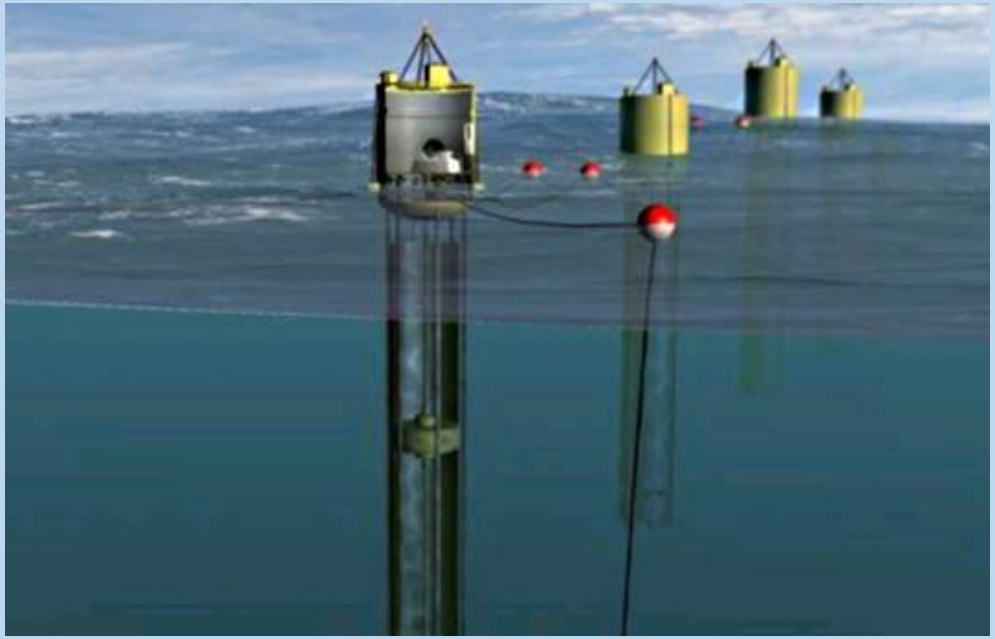


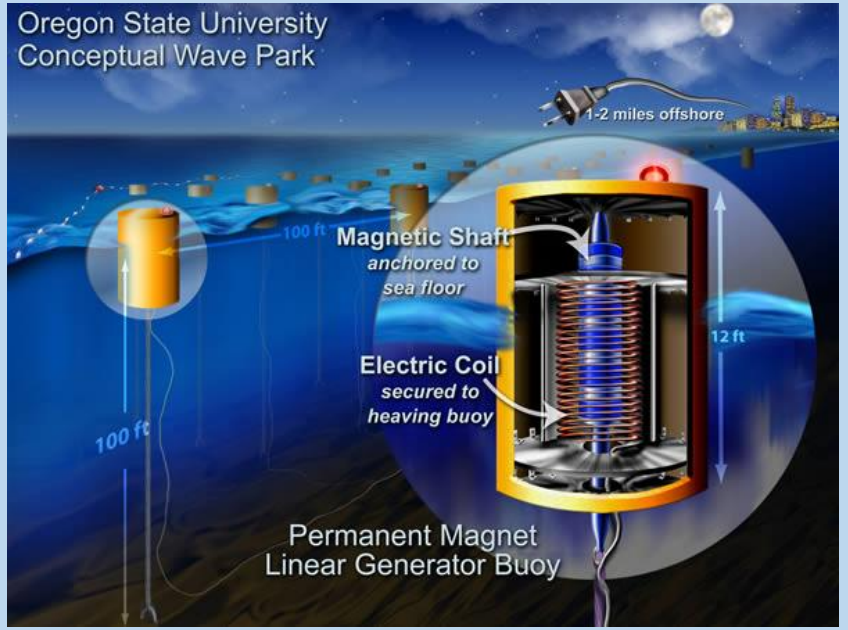
Graphics courtesy of Voith Hydro

Developing Hydropower Technologies

Wave

- Wave motion - buoy



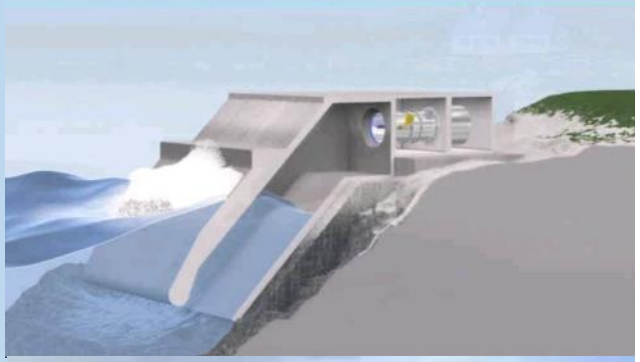


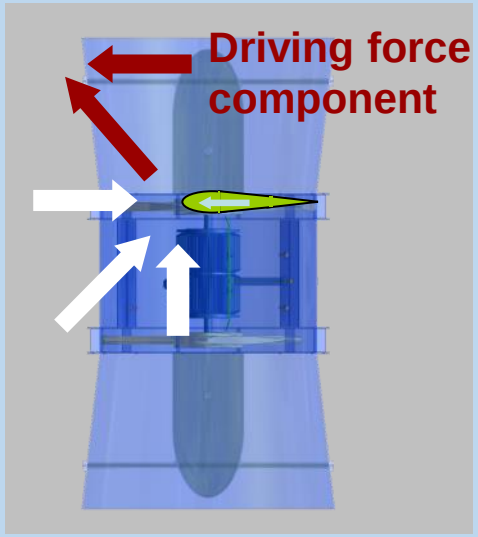
Courtesy *Aquabuoy* system

New Hydropower Technologies

Wave

- Wave surge compressing air as it runs through air turbine





Wavegen
A Voith and Siemens Company

Developing Hydropower Technologies

In Stream / Hydro Kinetic

- Kinetic energy of the current is harnessed

Courtesy of Hydro Green Energy, LLC

Project at Hastings, MN

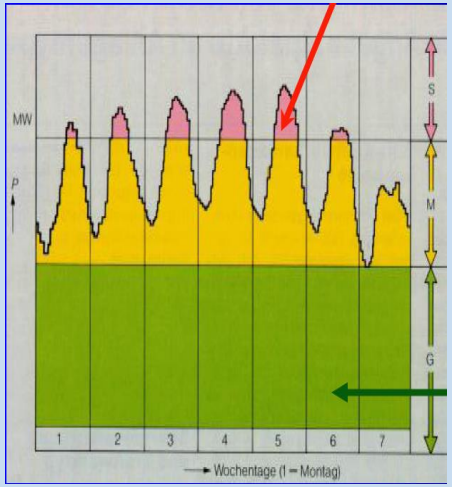
Hydro+™,

Current Issues – The Grid

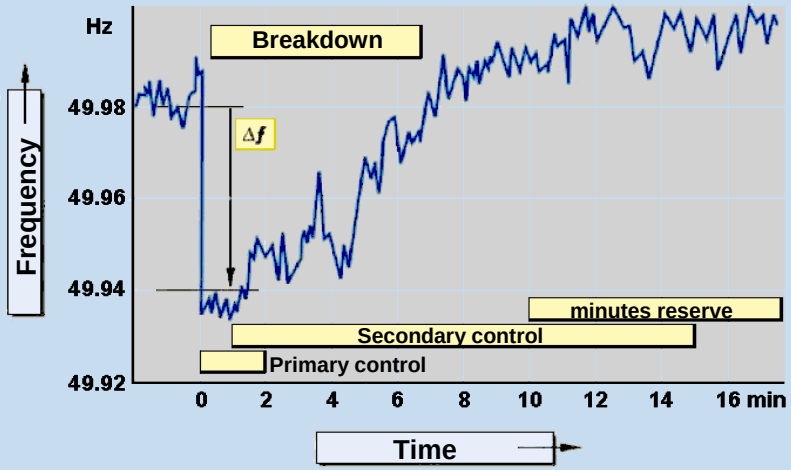
Wind, Solar and Hydro Integration

When the wind is not blowing or the sun is not shining, pump storage can act as a large battery.

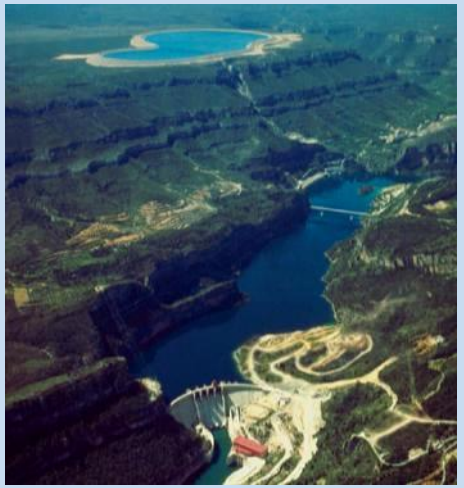
- Reserves
- Frequency regulation



Energy

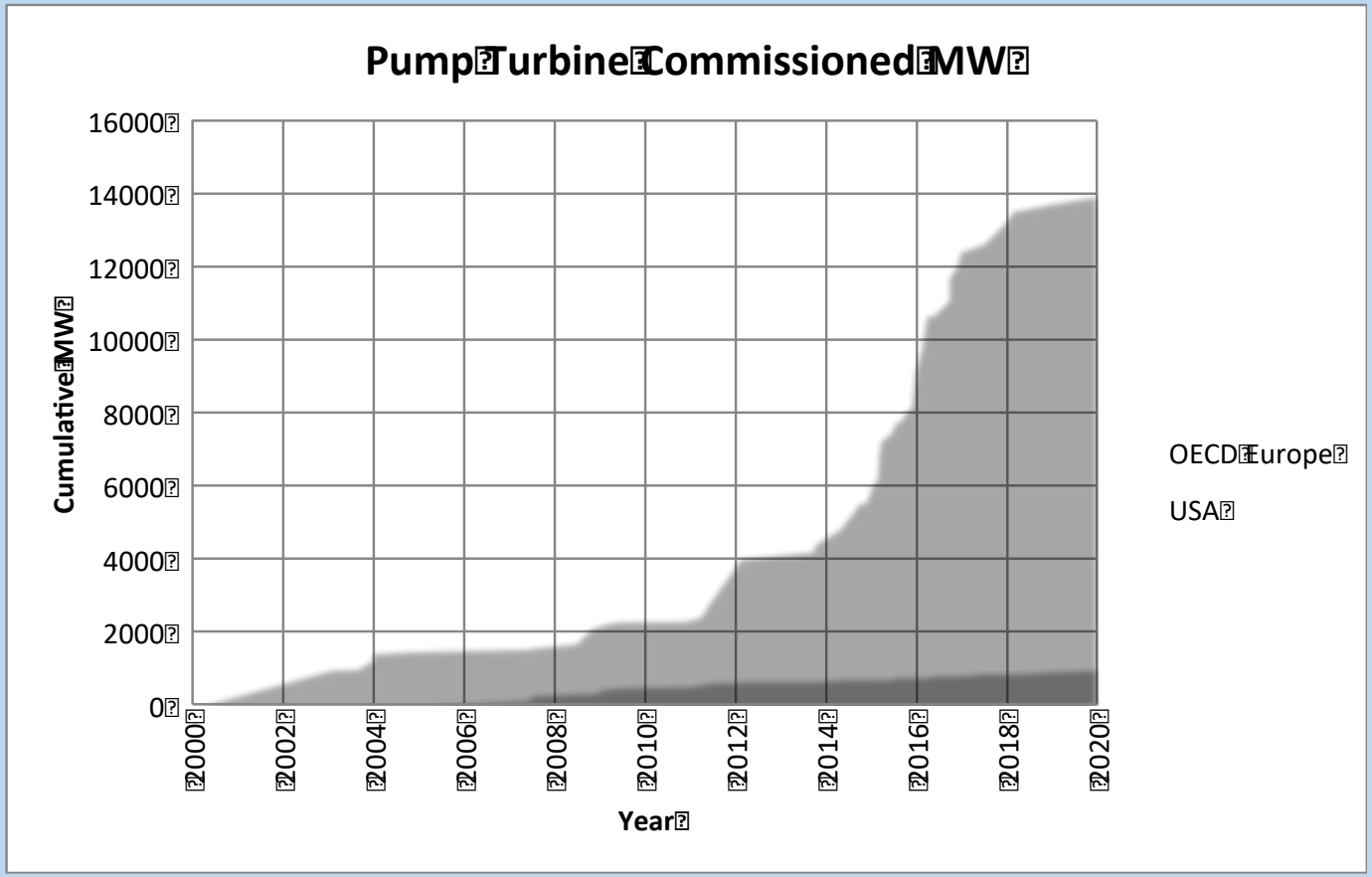


Frequency



Storage

Pumped Storage Growth, U.S. vs. Europe



wrap-up

Google

california electric car mandate

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Yes. California is only requiring that all NEW cars sold in 2035 and beyond are zero-emission vehicles which includes battery electric vehicles, plug-in hybrid electric vehicles and fuel cell electric vehicles.

CA.gov
https://ww2.arb.ca.gov › resources › documents › cars-a...

Cars and Light-Trucks are Going Zero - Frequently Asked ...

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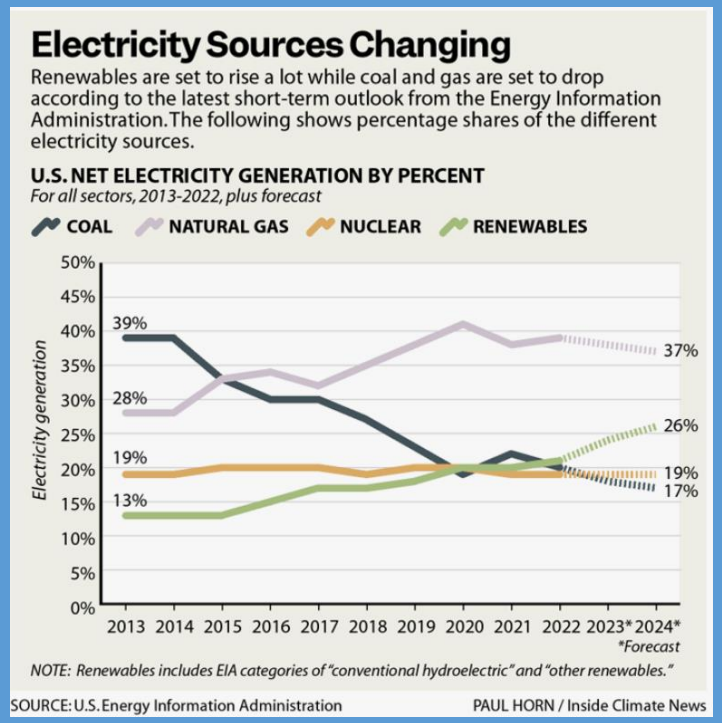
You're Gonna Need…



We're Gonna Need…

Increased hydro capacity meeting future demand by

- ***upgrading existing hydro stations and leveraging existing infrastructure***
- ***Increasing unit availability by decreasing unit forced outages and planned maintenance outage durations***

Increased energy storage capacities by

- ***recognizing the economic value of pumped-storage hydro storage/ancillary services and high-capacity battery lifecycle***

Faster reacting generators and turbine by

- ***integrating technology and machine design***

Faster reacting electric grid protection systems by

- ***installing faster cyber-secured communication systems and devices***

- National Hydropower Association
  http://www.hydro.org
- Federal Energy Regulatory Commission
  http://www.ferc.gov/industries/hydropower.asp
- Canadian Hydropower Association
  https://canadahydro.ca
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