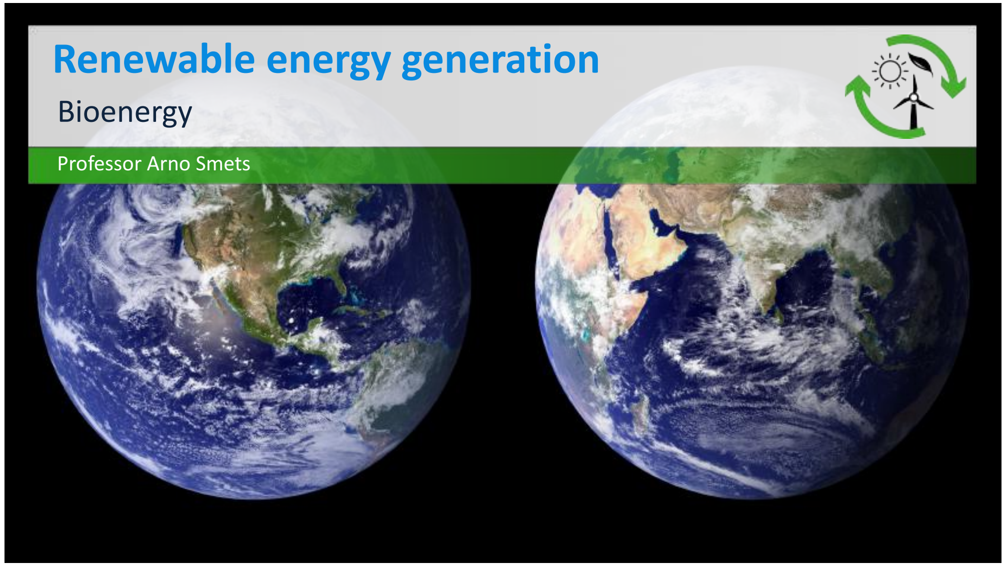
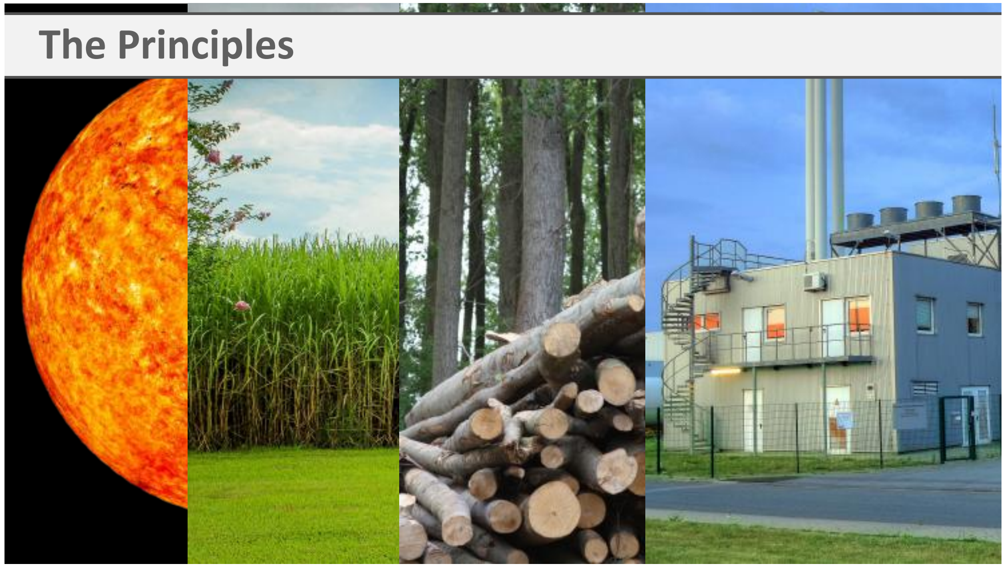
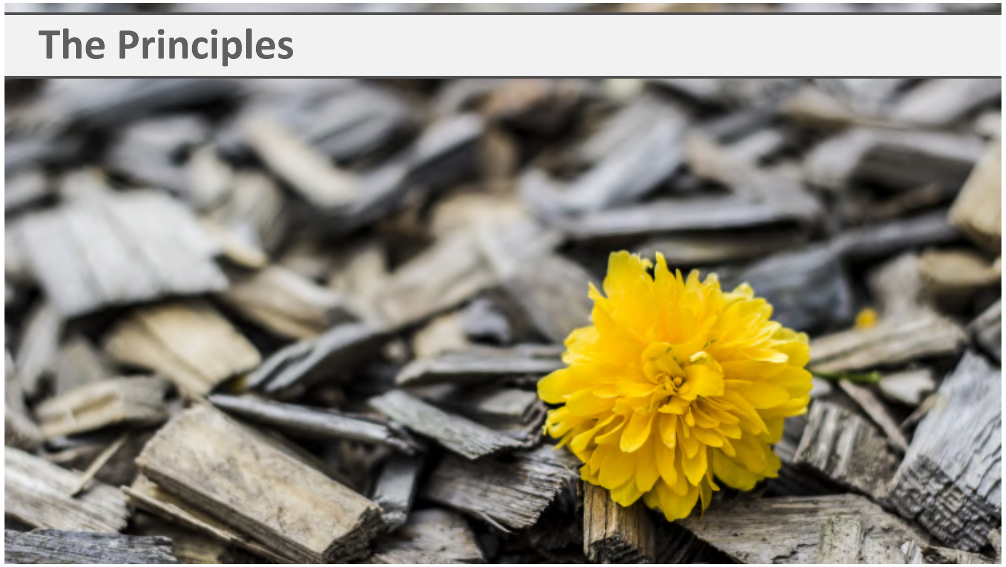

Renewable energy generation
Bioenergy
Professor Arno Smets


Bioenergy Technology


The Principles


The Principles

The Principles

PRIMARY ENERGY POTENTIAL

$$E_{sun} = E_{rad} * A \qquad [\mathrm{J}] = [\mathrm{J\ m^{-2}}] * [\mathrm{m^2}]$$

$$P_{sun} = {E_{sun}}/{t} = I_e * A \qquad [\mathrm{W}] = [\mathrm{W\ m^{-2}}] * [\mathrm{m^2}]$$

SYSTEM EFFICIENCIES

Photosynthetic Efficiency

Thermal Conversion Efficiency

Chemical Conversion Efficiency

ENERGY YIELD

Type of Crop

Seasonal Changes

Calculation Example

Given Information

$E_{Rad} = 1500\ [\mathrm{kWh\ m^{-2}}]$ $\quad \eta_{photosynthesis} = 0.4\%$ $\quad \eta_{Thermal} = 25\%$

Calculate Yield

$E_{Yield} = 0.004 * 0.25 * \ 1500\ [\mathrm{kWh\ m^{-2}}] = 1.5\ [\mathrm{kWh\ m^{-2}}]$

Calculate Power

$P_{ave} = 1.5\ [\mathrm{kWh\ m^{-2}}] * {}^{1}/_{8760} = 0.17\ [\mathrm{W\ m^{-2}}]$

Calculation Example

Given Information

$I_e = 230\ [\mathrm{W\ m^{-2}}]$ $\quad \eta_{photosynthesis} = 1.5\ \%$ $\quad \eta_{conversion1} = 30\%$

$\eta_{conversion2} = 75\%$

Calculate Power

$P_{ave} = 0.015 * 0.30 * 0.75 * 230\ [\mathrm{W\ m^{-2}}] = 0.78\ [\mathrm{W\ m^{-2}}]$

Calculation Example: Drax Power Station, UK

Given Information

Nominal Capacity = $1320\ [\mathrm{MW}]$ & Energy Yield = $7.9\ [\mathrm{TWh}]$

Calculate Capacity Factor

$Cf = 7.9[\mathrm{TWh\ year^{-1}}] * {}^{1}/_{8760}\ [\mathrm{year\ h^{-1}}] * {}^{1}/_{1320}\ [\mathrm{MW^{-1}}] = 0.68$

ADVANTAGES	CHALLENGES
• Storage Possibility • Ethanol can be used almost equally as gasoline • High Energy density of Ethanol	• 1st Gen competes with land & food

ADVANTAGES	CHALLENGES
• Storage Possibility • Ethanol can be used almost equally as gasoline • High Energy density of Ethanol	• 1st Gen competes with land & food • Net energy gain is low • Relatively high carbon footprint

Global Perspective: Electricity

Given Information

Global Energy Yield= $433\ [\mathrm{TWh\ year^{-1}}]$ Global Population = $7.5 * 10^9 [\mathrm{person}]$

Other Units

$$E_{GlobalYield} = 433\ [\mathrm{TWh\ year^{-1}}] * {}^{1}/_{7.5\ *\ 10^9}\ [\mathrm{person^{-1}}] * {}^{1}/_{365}\ [\mathrm{year\ day^{-1}}]$$

$$E_{GlobalYield} = 158\ [\mathrm{Wh\ person^{-1} day^{-1}}]$$

Global Perspective: Thermal Capacity

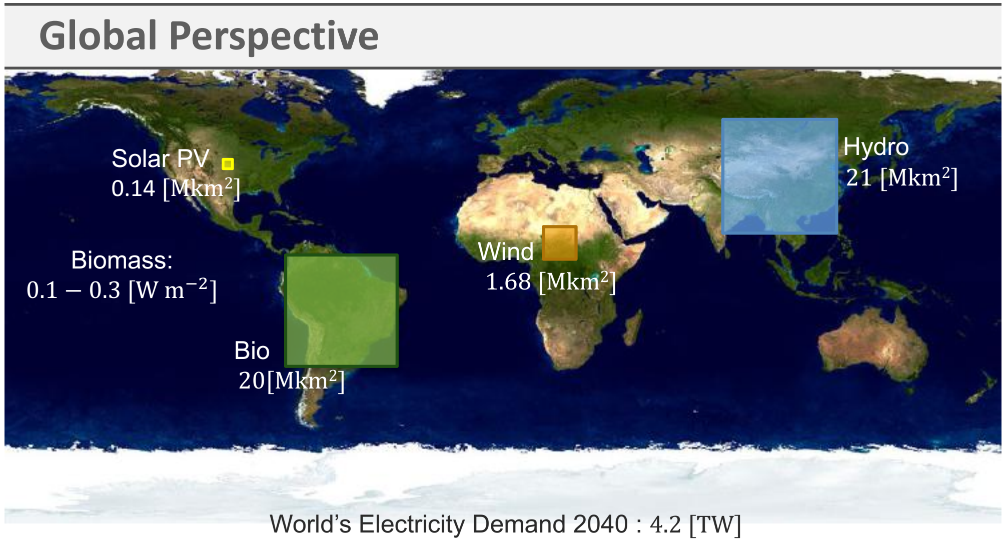
Given Information

Global Energy Yield= $2300\ [TWh\ year^{-1}]$ Global Population = $7.5 * 10^9 [\mathrm{person}]$

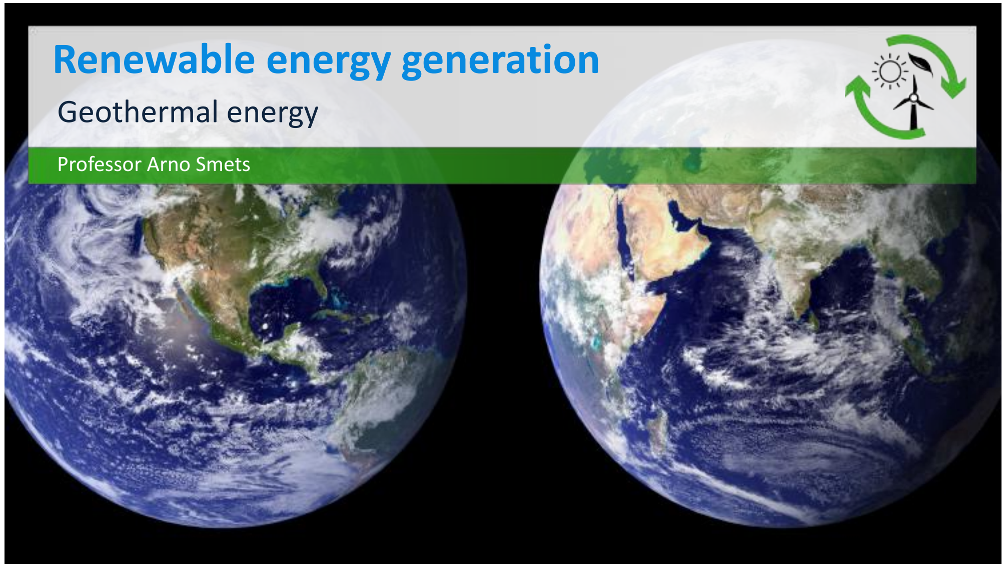
Other Units

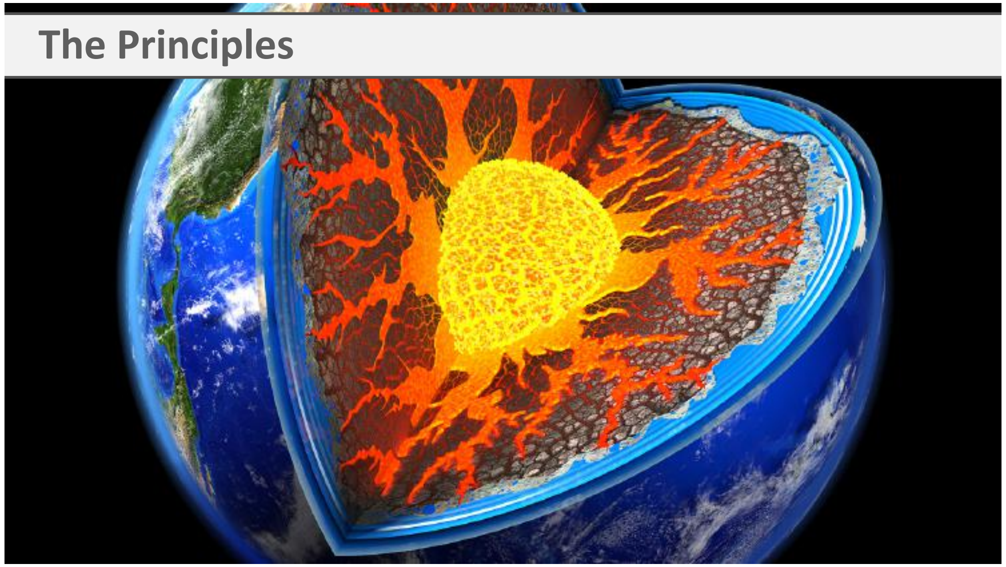
$$E_{GlobalYield} = 2300\ [\mathrm{TWh\ year^{-1}}] * {}^{1}/_{7.5\ *\ 10^9}\ [\mathrm{person^{-1}}] * {}^{1}/_{365}\ [\mathrm{year\ day^{-1}}]$$

$$E_{GlobalYield} = 840\ [\mathrm{Wh\ person^{-1} day^{-1}}]$$

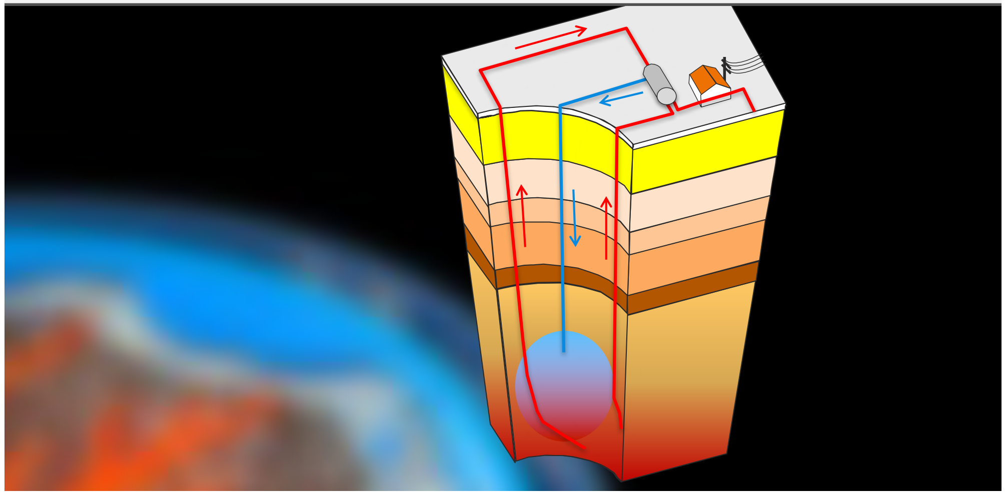

Global Perspective
Solar PV
0.14 [Mkm²]
Hydro
21 [Mkm²]
Biomass:
0.1 – 0.3 [W m⁻²]
Wind
1.68 [Mkm²]
Bio
20[Mkm²]
World's Electricity Demand 2040 : 4.2 [TW]


Thank you for your attention!

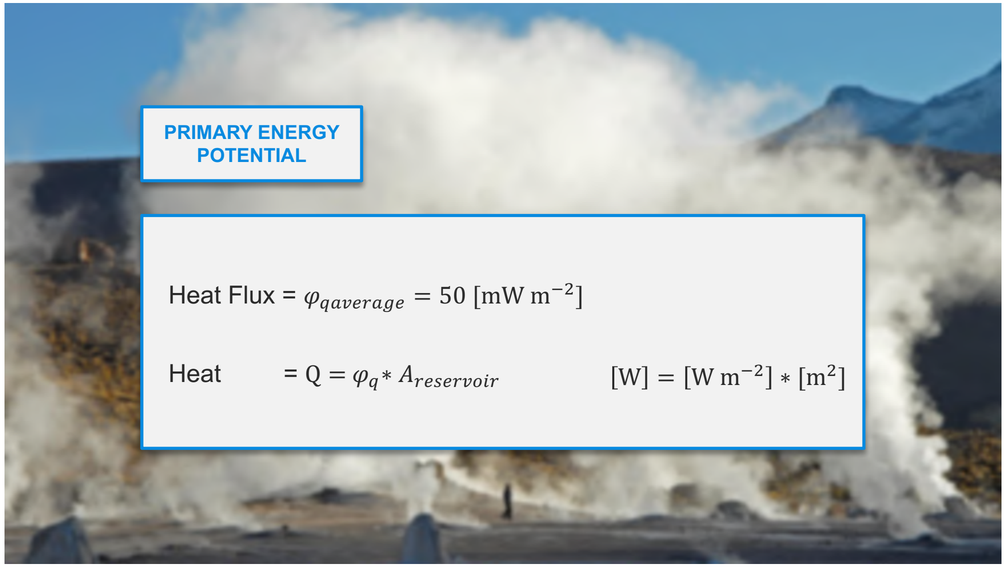

Renewable energy generation
Geothermal energy
Professor Arno Smets


The Principles

The Principles



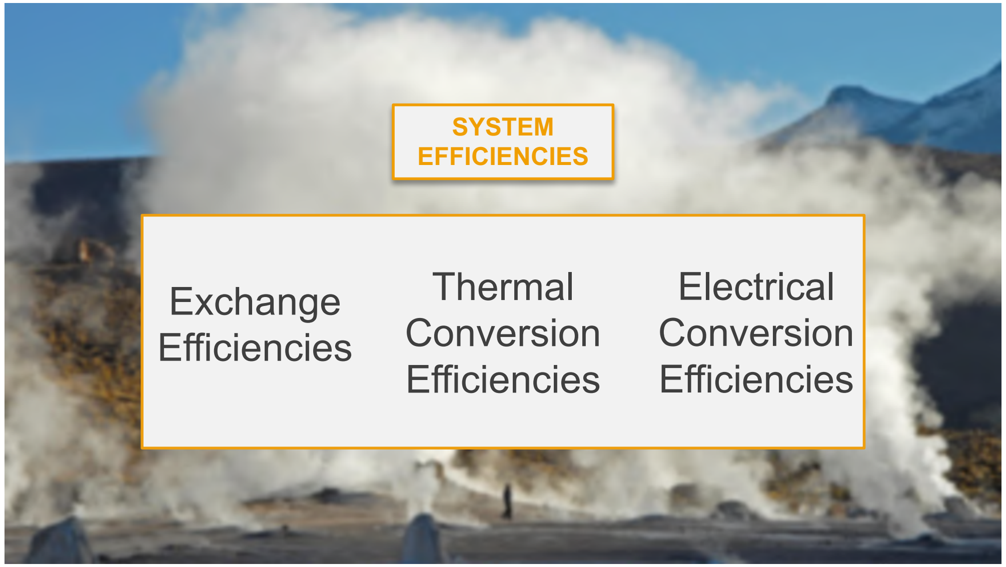
The Principles

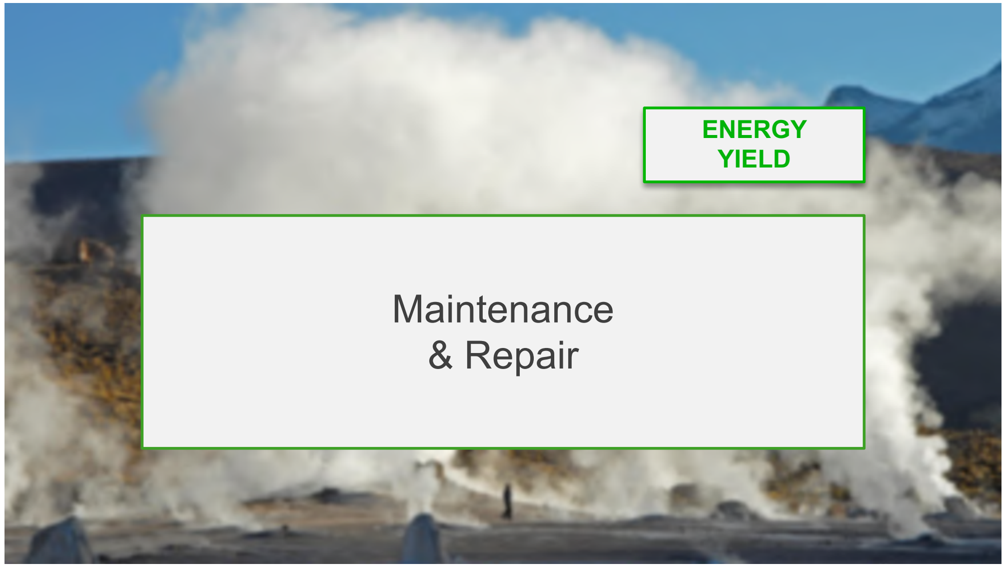


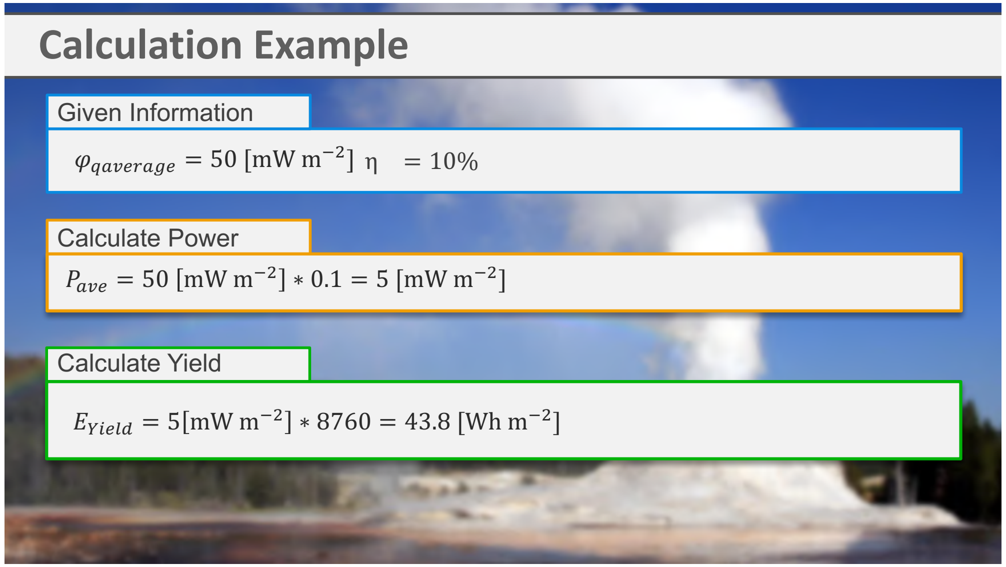
PRIMARY ENERGY POTENTIAL

Heat Flux = $\varphi_{qaverage} = 50\ [\mathrm{mW\ m^{-2}}]$

Heat = $Q = \varphi_q * A_{reservoir}$ $[\mathrm{W}] = [\mathrm{W\ m^{-2}}] * [\mathrm{m^2}]$


SYSTEM EFFICIENCIES
Exchange Efficiencies
Thermal Conversion Efficiencies
Electrical Conversion Efficiencies


ENERGY YIELD
Maintenance & Repair


Calculation Example
Given Information
$\varphi_{qaverage} = 50\ [\mathrm{mW\ m^{-2}}]\ \eta \ = 10\%$
Calculate Power
$P_{ave} = 50\ [\mathrm{mW\ m^{-2}}] * 0.1 = 5\ [\mathrm{mW\ m^{-2}}]$
Calculate Yield
$E_{Yield} = 5[\mathrm{mW\ m^{-2}}] * 8760 = 43.8\ [\mathrm{Wh\ m^{-2}}]$

Calculation Example: Hellisheiði Power Station

Given Information

Nominal Capacity = $303[\mathrm{MW}]$ & Energy Yield = $2.3[\mathrm{TWh}]$

Calculate Capacity Factor

$$Cf = 2.3[\mathrm{TWh\ year^{-1}}] * {}^{1}/_{8760}\ [\mathrm{year\ h^{-1}}] * {}^{1}/_{303}\ [\mathrm{MW^{-1}}] = 0.87$$

ADVANTAGES

- Base Load for Grid
- Long Lifetime of 30 years
- Land use is small

CHALLENGES

- Not all Locations suitable
- Drilling is expensive

Global Perspective

Given Information

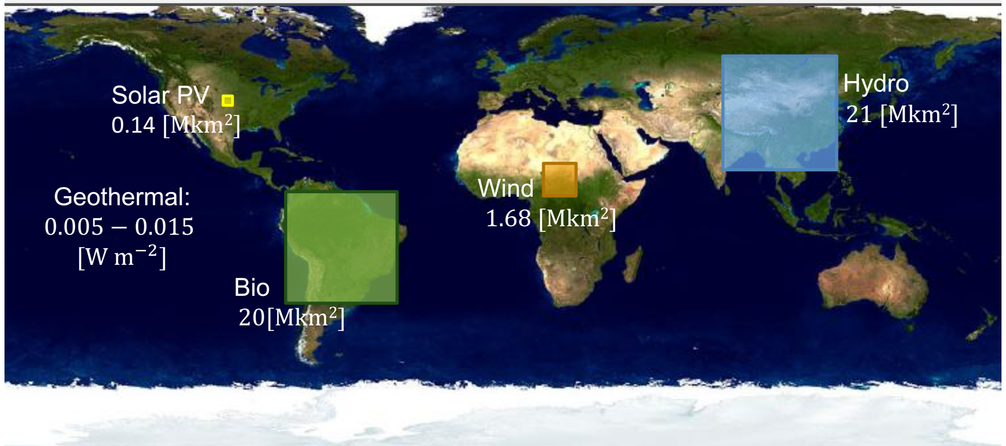
Global Energy Yield= $89.6\ [\mathrm{TWh\ year^{-1}}]$ Global Population= $7.5 * 10^{9}[\mathrm{person}]$

Other Units

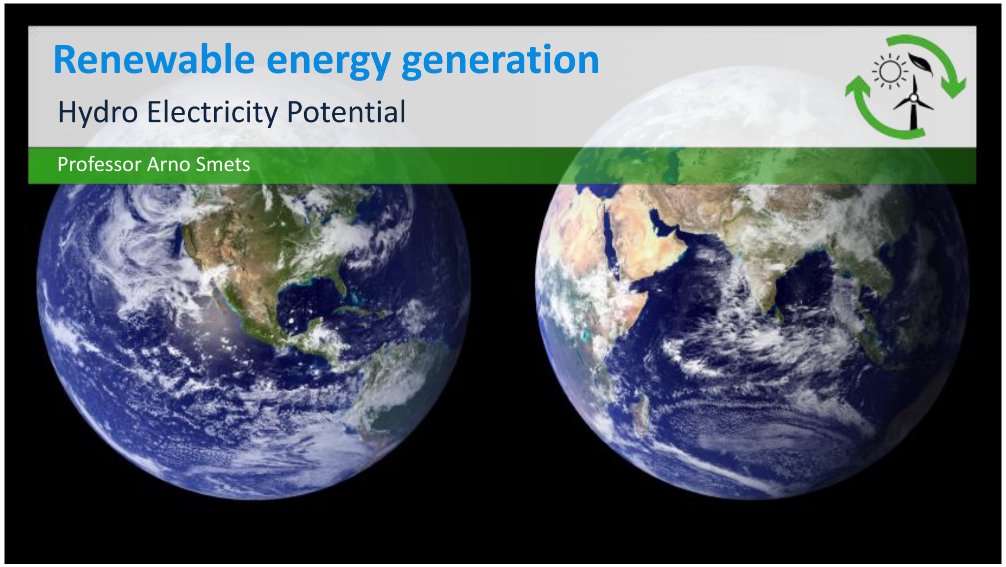
$$E_{GlobalYield} = 89.6\ [\mathrm{TWh\ year^{-1}}] * {}^{1}/_{7.5\ *\ 10^{9}}\ [\mathrm{person^{-1}}] * {}^{1}/_{365}\ [\mathrm{year\ day^{-1}}]$$

$$E_{GlobalYield} = 32.7\ [\mathrm{Wh\ person^{-1} day^{-1}}]$$

Global Perspective



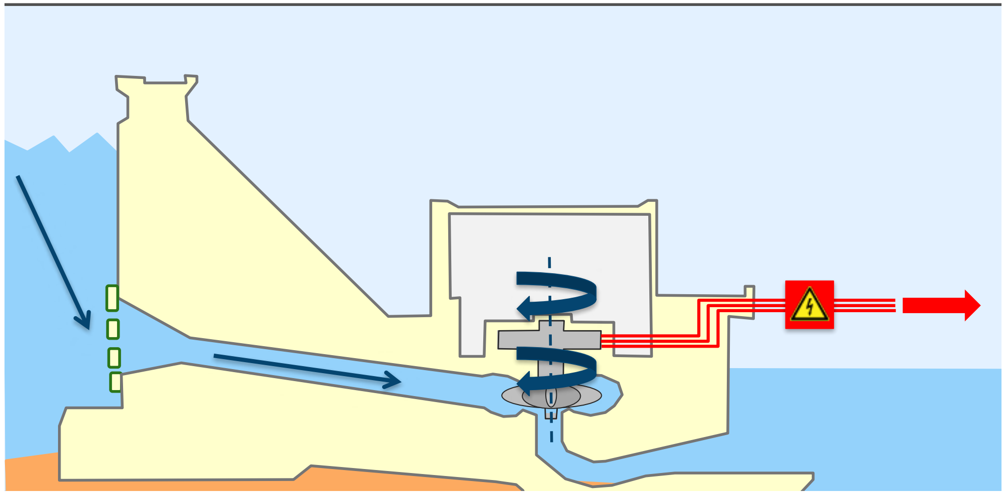
World's Electricity Demand 2040 : 4.2 [TW]

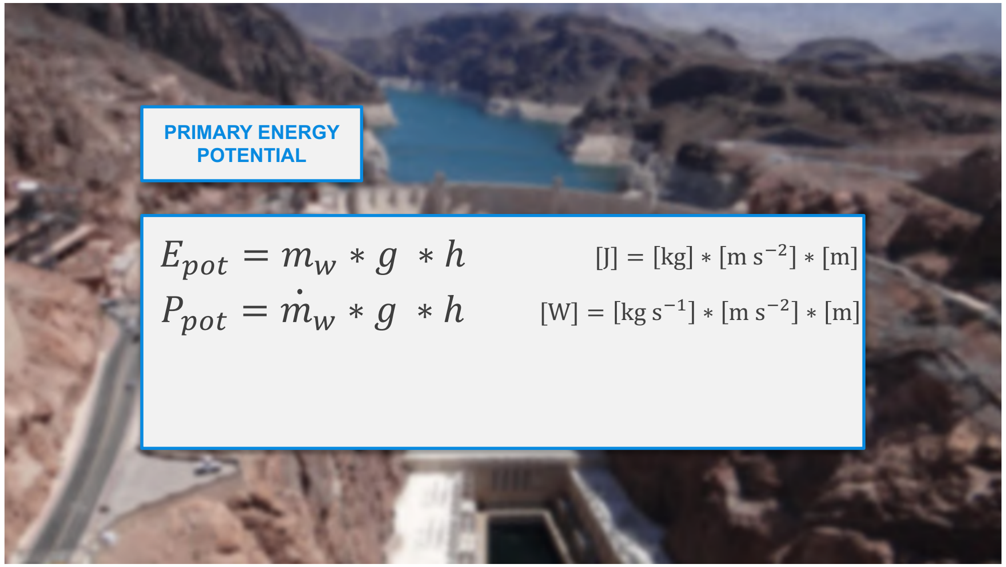


Hydro Electricity

The Principles

The Principles

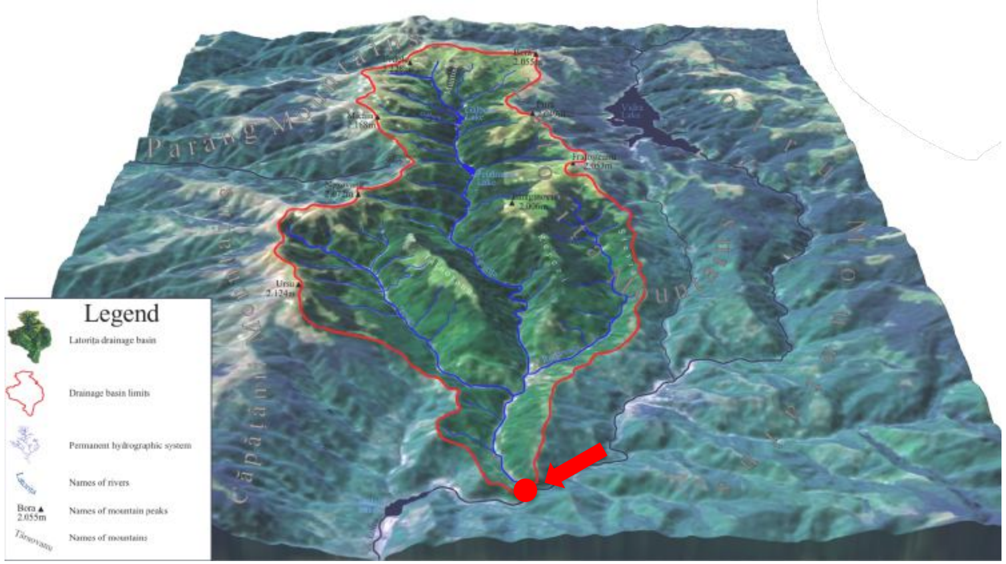


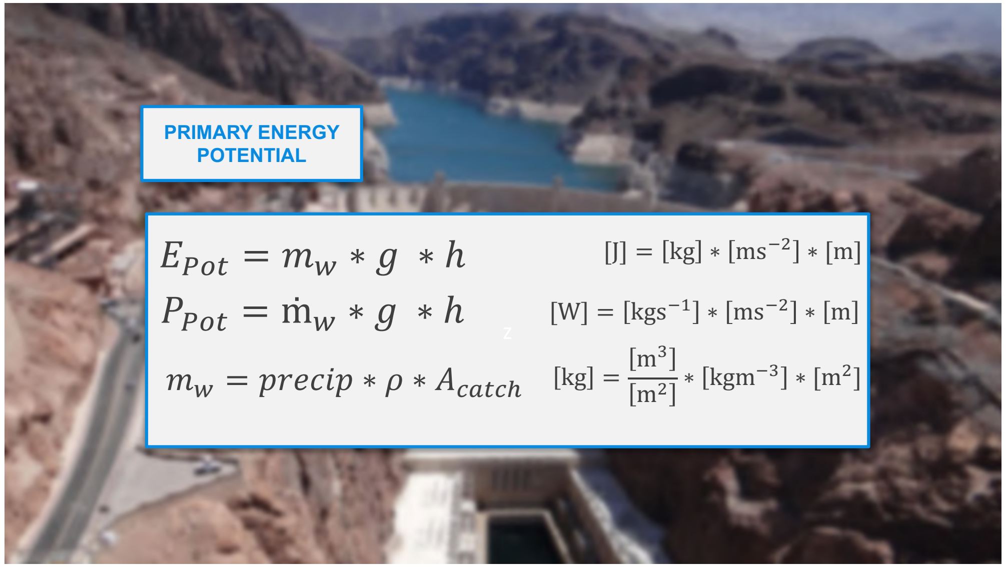


PRIMARY ENERGY POTENTIAL

$$E_{pot} = m_w * g * h \qquad [\mathrm{J}] = [\mathrm{kg}] * [\mathrm{m\,s^{-2}}] * [\mathrm{m}]$$

$$P_{pot} = \dot{m}_w * g * h \qquad [\mathrm{W}] = [\mathrm{kg\,s^{-1}}] * [\mathrm{m\,s^{-2}}] * [\mathrm{m}]$$

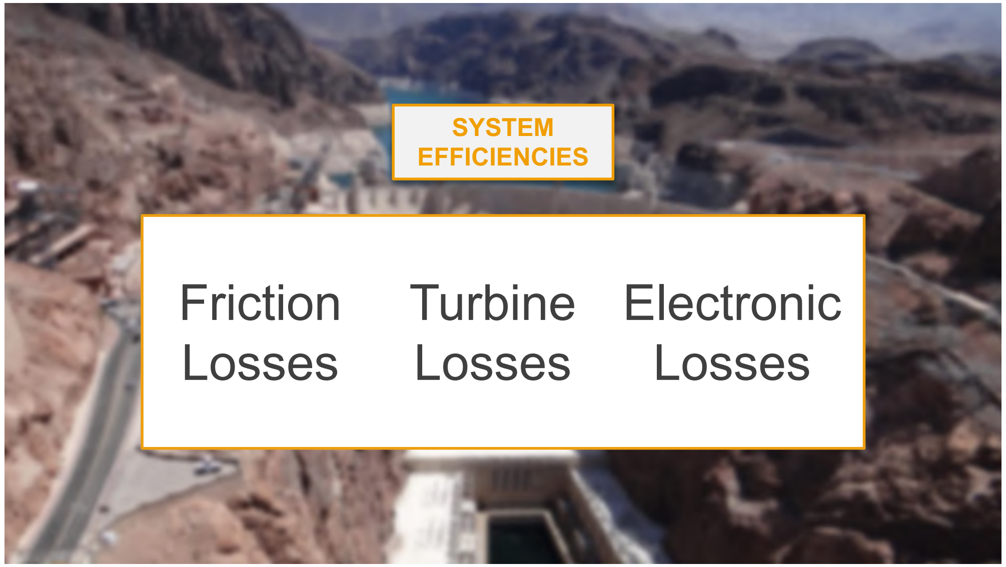




$$E_{Pot} = m_W * g * h \qquad [J] = [kg] * [ms^{-2}] * [m]$$

$$P_{Pot} = \dot{m}_W * g * h \qquad [W] = [kgs^{-1}] * [ms^{-2}] * [m]$$

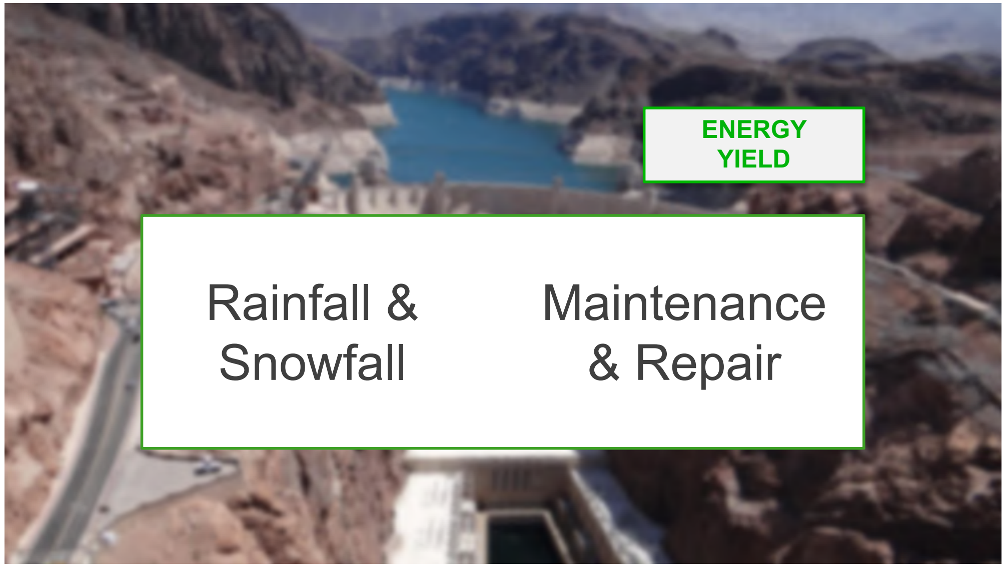
$$m_W = precip * \rho * A_{catch} \qquad [kg] = \frac{[m^3]}{[m^2]} * [kgm^{-3}] * [m^2]$$



Friction Losses

Turbine Losses

Electronic Losses



Rainfall & Snowfall

Maintenance & Repair

Calculation Example

Given Information

Rainfall = $500\ [\mathrm{mm}]$ & Height $\mathrm{h} =\ 100\ [\mathrm{m}]$

Gather Useful Values

$$Precipitation = 500\ [\mathrm{mm^3\ mm^{-2}}] * 10^{-3} [\mathrm{m\ mm^{-1}}] = 0.5 [\mathrm{m^3\ m^{-2}}]$$

$$Mass = m_w \quad = 0.5\ [\mathrm{m^3\ m^{-2}}] * 1000 [\mathrm{kg\ m^{-3}}] = 500\ [\mathrm{kg\ m^{-2}}]$$

Calculate Potential

$$Energy = E_{Pot} = 500\ [\mathrm{kg\ m^{-2}}] * 9.81\ [\mathrm{m\ s^{-2}}] * 100\ [\mathrm{m}] = 490\ [\mathrm{kJ\ m^{-2}}]$$

Calculation Example

Calculate Potential

$$Energy = E_{Pot} = 500\ [\mathrm{kg\ m^{-2}}] * 9.81\ [\mathrm{m\ s^{-2}}] * 100\ [\mathrm{m}] = 490\ [\mathrm{kJ\ m^{-2}}]$$

Other Units

$$E_{Pot} \quad = 490\ [\mathrm{kJ\ m^{-2}}] * {}^{1}\!/_{(60 * 60 * 24 * 365)} [\mathrm{year\ s^{-1}}] * (24 * 365) [\mathrm{h\ year^{-1}}]$$
$$= 136\ [\mathrm{Wh\ m^{-2}}]$$

Calculate Power

$$P_{Pot} = 136\ [\mathrm{Wh\ m^{-2}}] * {}^{1}\!/_{8760}\ [\mathrm{h^{-1}}] = 0.016\ [\mathrm{W\ m^{-2}}]$$

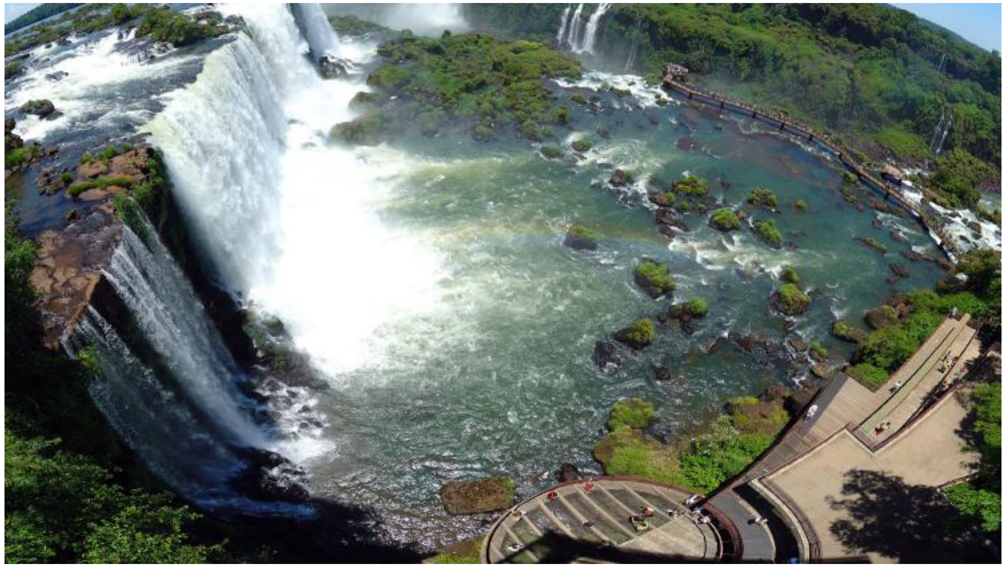
Calculation Example: Itaipu Dam, Brazil

Given Information

Installed Capacity = $14[\mathrm{GW}]$ & Energy Yield = $89.5[\mathrm{TWh}]$

Calculate Capacity Factor

$$Cf = 89.5 [\mathrm{TWh\ year^{-1}}] * {}^{1}\!/_{8760}\ [h\ year^{-1}] * {}^{1}\!/_{14}\ [\mathrm{GW^{-1}}] = 0.73$$



ADVANTAGES

- Storage
- Support to the grid
- Stable power source
- Life time of 30 to 100 years

CHALLENGES

Impact on:
- Flora
- Fauna
- Landscape
- Local Climate

Global Perspective

Given Information

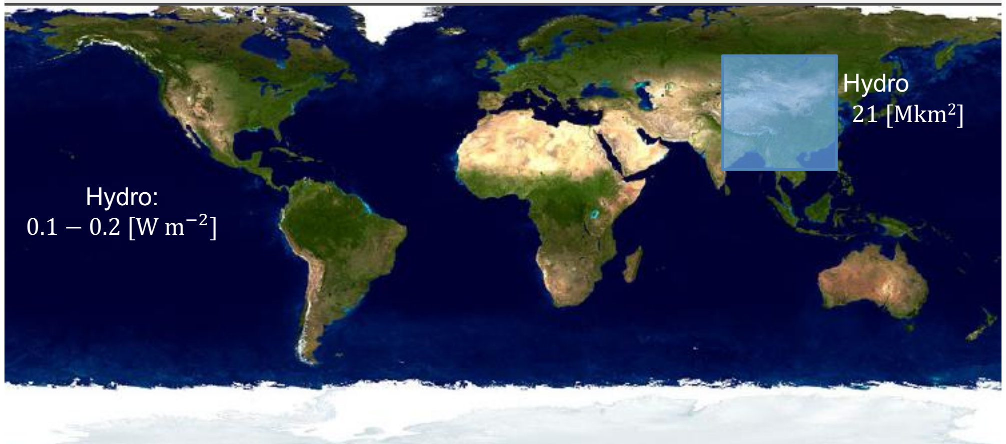
Global Energy Yield= $3975\ [\mathrm{TWh\ year^{-1}}]$ Global Population = $7.5 * 10^{9} [\mathrm{person}]$

Other Units

$$E_{GlobalYield} = 3975\ [\mathrm{TWh\ year^{-1}}] * {}^{1}/_{7.5\ *\ 10^{9}}\ [\mathrm{person^{-1}}] * {}^{1}/_{365}\ [\mathrm{year\ day^{-1}}]$$

$$E_{GlobalYield} = 1.45\ [\mathrm{kWh\ person^{-1} day^{-1}}]$$

Global Perspective



World's Electricity Demand 2040 : $4.2\ [\mathrm{TW}]$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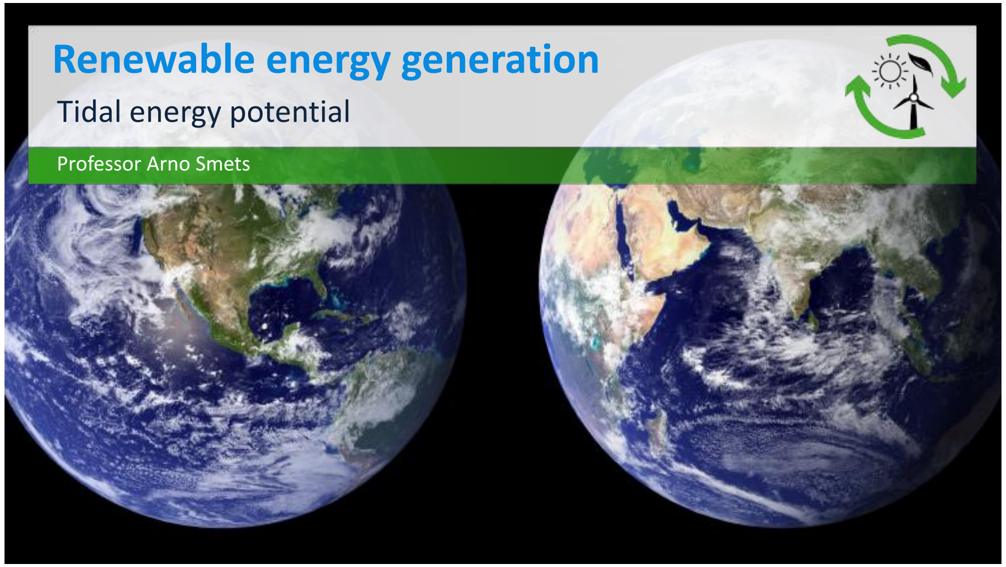
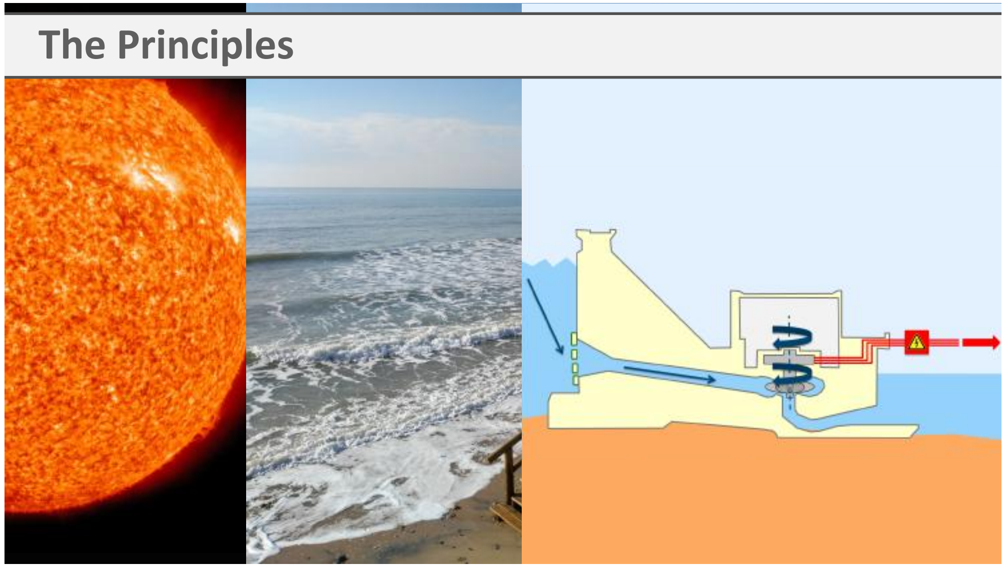
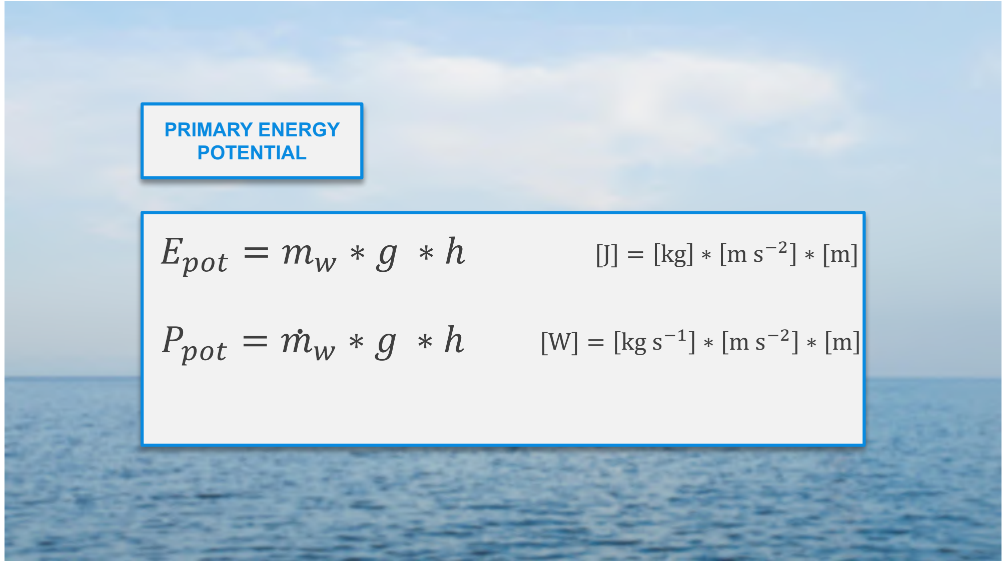
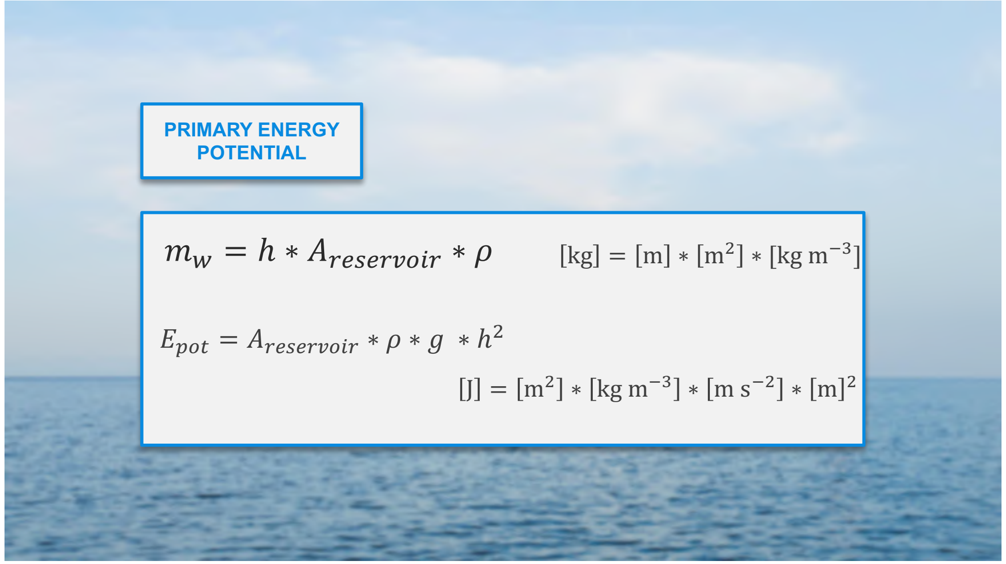
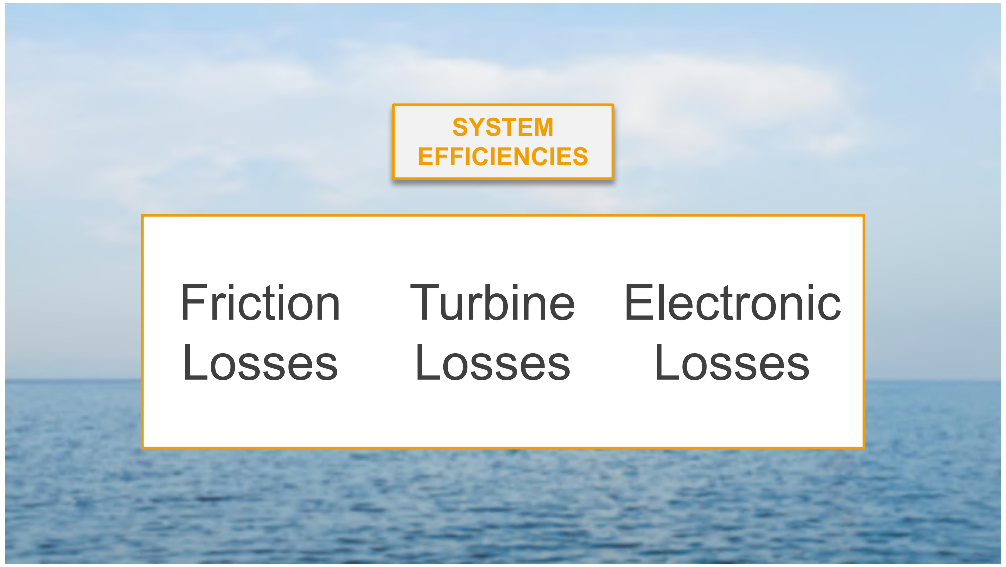
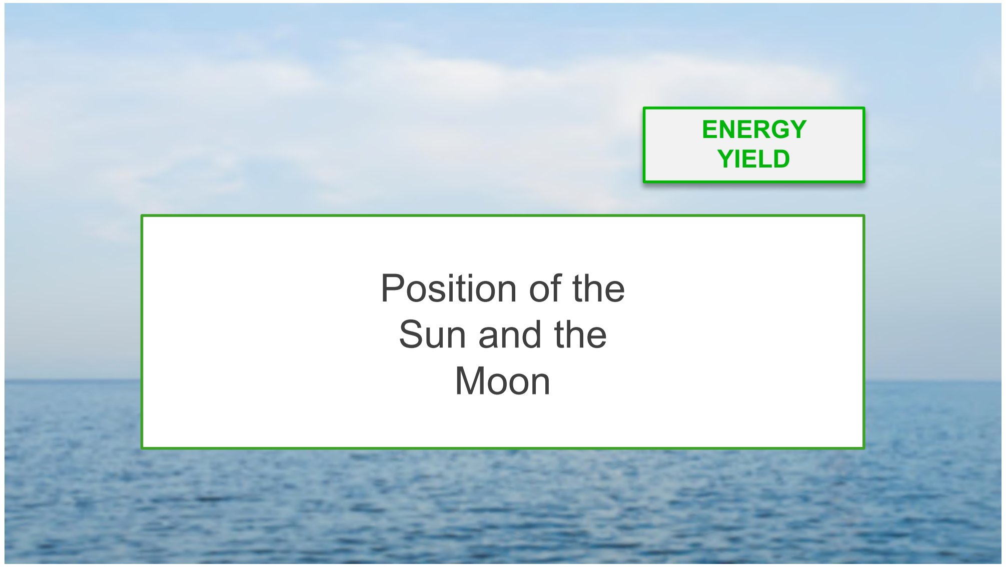

Renewable energy generation
Tidal energy potential
Professor Arno Smets

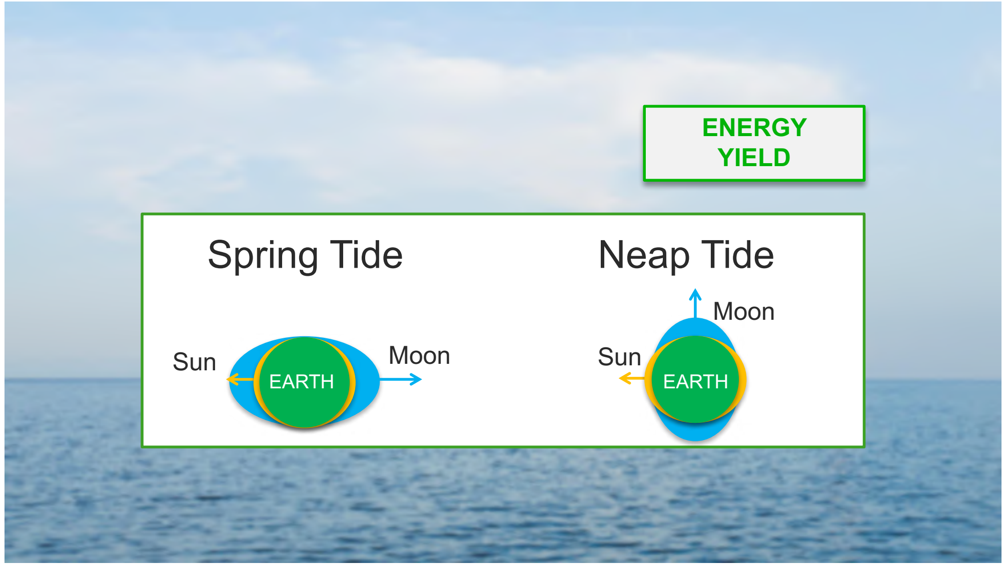

The Principles


PRIMARY ENERGY POTENTIAL
$E_{pot} = m_w * g * h$ $\quad [\mathrm{J}] = [\mathrm{kg}] * [\mathrm{m\,s^{-2}}] * [\mathrm{m}]$
$P_{pot} = \dot{m}_w * g * h$ $\quad [\mathrm{W}] = [\mathrm{kg\,s^{-1}}] * [\mathrm{m\,s^{-2}}] * [\mathrm{m}]$


PRIMARY ENERGY POTENTIAL
$m_w = h * A_{reservoir} * \rho$ $\quad [\mathrm{kg}] = [\mathrm{m}] * [\mathrm{m^2}] * [\mathrm{kg\,m^{-3}}]$
$E_{pot} = A_{reservoir} * \rho * g * h^2$
$[\mathrm{J}] = [\mathrm{m^2}] * [\mathrm{kg\,m^{-3}}] * [\mathrm{m\,s^{-2}}] * [\mathrm{m}]^2$


SYSTEM EFFICIENCIES
Friction Losses
Turbine Losses
Electronic Losses


ENERGY YIELD
Position of the Sun and the Moon



Calculation Example

Given Information

$h = 10\ [\mathrm{m}]\quad \&\ A_{column} = 1\ [\mathrm{m}^2]$

Gather Values

$\rho = 1025\ [\mathrm{kg\ m^{-3}}]\qquad g = 9.81\ [\mathrm{m\ s^{-2}}]$

Calculate Potential

$$E_{Pot} = 1[\mathrm{m}^2] * 1025\ [\mathrm{kg\ m^{-3}}] * 9.81\ [\mathrm{m\ s^{-2}}] * 10^2[\mathrm{m}]^2 = 1[\mathrm{MJ}]$$
$$= 0.27\ [\mathrm{kWh}]$$

Calculation Example

Energy per tide

$E_{Pot} = 0.27\ [\mathrm{kWh\ \ m^{-2}\ tide^{-1}}]$

Energy per day

$E_{Potdaily} = 0.27\ [\mathrm{kWh\ m^{-2}\ tide^{-1}}] * 2\ [\mathrm{tide\ day^{-1}}] = 0.55\ [\mathrm{kWh\ m^{-2}\ day^{-1}}]$

Calculate Average Power

$P_{ave} = 0.55\ [\mathrm{kWh\ m^{-2} day^{-1}}] * {}^{1}/_{24}\ [\mathrm{day\ h^{-1}}] = 22.7\ [\mathrm{W\ m^{-2}}]$

Calculation Example: Rance Tidal Power Station

Given Information

Nominal Capacity = $240[\mathrm{MW}]$ & Energy Yield = $500[\mathrm{GWh}]$

& $\mathrm{h} = 8\ [\mathrm{m}]$ & $A_{reservoir} = 22.5\ [\mathrm{km}^2]$

Calculate Capacity Factor

$$Cf = 500[\mathrm{GWh\ year}^{-1}] * {}^{1}/_{8760}\ [\mathrm{year\ h}^{-1}] * {}^{1}/_{240}\ [\mathrm{MW}^{-1}] = 0.24$$

Calculate Average Output Power

$$P_{ave.output} = 240\ [\mathrm{MW}\ ] * 0.24 * {}^{1}/_{22.5}\ [\mathrm{km}^{-2}] = 2.6\ [\mathrm{W\ m}^{-2}]$$

Calculation Example: Rance Tidal Power Station

Given Information

$$h = 8\ [\mathrm{m}]$$

Calculate Potential Energy

$$E_{Pot} = 1025\ [\mathrm{kg\ m}^{-3}] * 9.81\ [\mathrm{m\ s}^{-2}] * 8^2[\mathrm{m}]^2 = 0.63[\mathrm{MJ\ m}^{-2}\ \mathrm{tide}^{-1}]$$

$$E_{Potdaily} = 0.63\ [\ \mathrm{MJ\ m}^{-2}\ \mathrm{tide}^{-1}] * 2\ [\mathrm{tide\ day}^{-1}] = 126\ [\mathrm{MJ\ m}^{-2}\ \mathrm{day}^{-1}]$$
$$= 0.35\ [\mathrm{kWh\ m}^{-2}\mathrm{day}^{-1}]$$

Calculate Average Potential Power

$$P_{ave.Pot} = 0.35\ [\mathrm{kWh\ m}^{-2}\mathrm{day}^{-1}] * {}^{1}/_{24}\ [\mathrm{day\ h}^{-1}] = 14.6\ [\mathrm{W\ m}^{-2}]$$

Calculation Example: Rance Tidal Power Station

Calculated Values

$P_{ave.Pot} = 14.6\ [\mathrm{W\ m}^{-2}]$ & $P_{ave.output} = 2.6\ [\mathrm{W\ m}^{-2}]$

Calculate Efficiency

$$\eta = 2.6\ [\mathrm{W\ m}^{-2}] * {}^{1}/_{14.6}\ [\mathrm{W\ m}^{-2}] = 18\%$$

ADVANTAGES	CHALLENGES
• Long Life Time • Tides are Predictable	• Generation is not continuous • Not all Locations Suitable • Impact on Environment

Global Perspective

Given Information

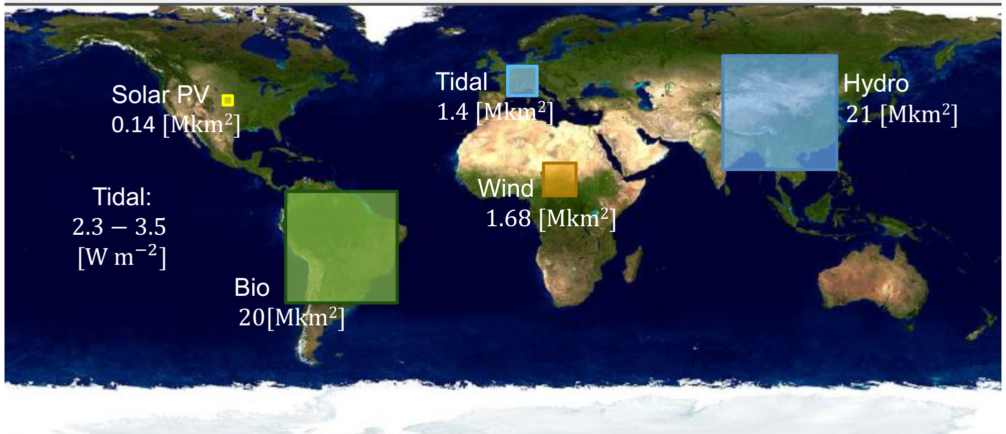
Global Energy Yield= $1.05\ [\mathrm{TWh\ year^{-1}}]$ Global Population $= 7.5 * 10^9 [\mathrm{person}]$

Other Units

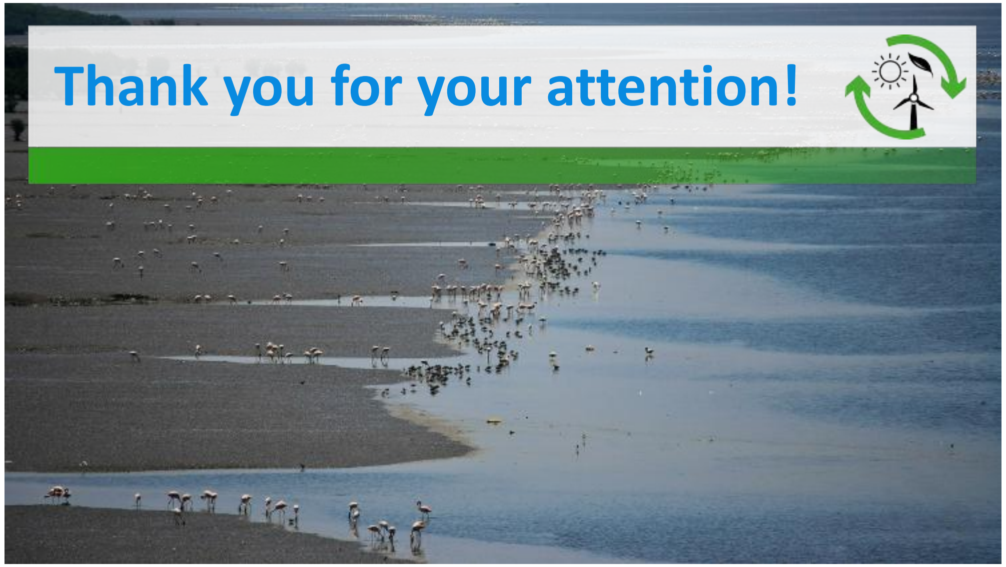
$$E_{GlobalYield} = 1.05\ [\mathrm{TWh\ year^{-1}}] * {}^{1}/_{7.5 * 10^9}\ [\mathrm{person^{-1}}] * {}^{1}/_{365}\ [\mathrm{year\ day^{-1}}]$$

$$E_{GlobalYield} = 0.38\ [\mathrm{Wh\ person^{-1} day^{-1}}]$$

Global Perspective



World's Electricity Demand 2040 : 4.2 [TW]



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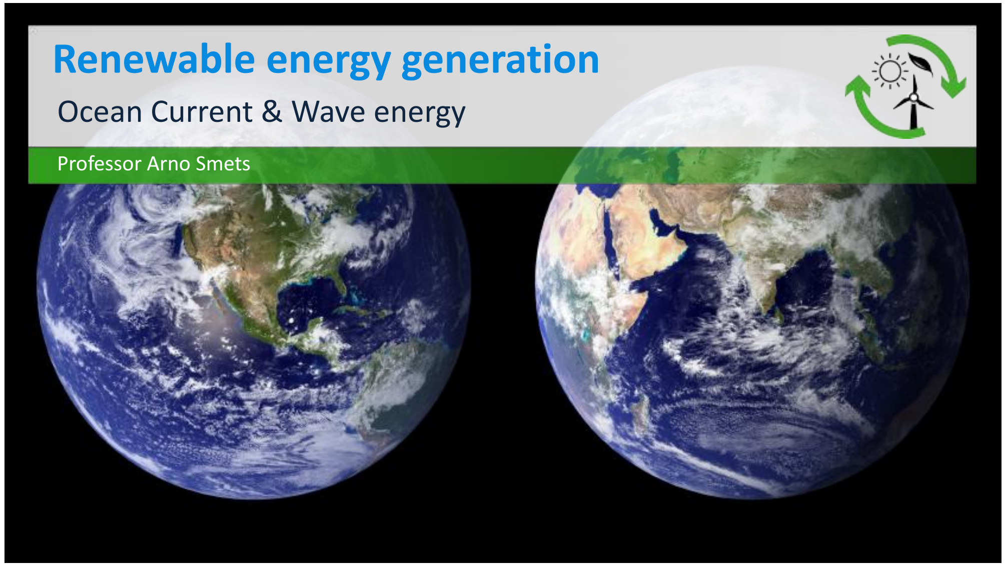
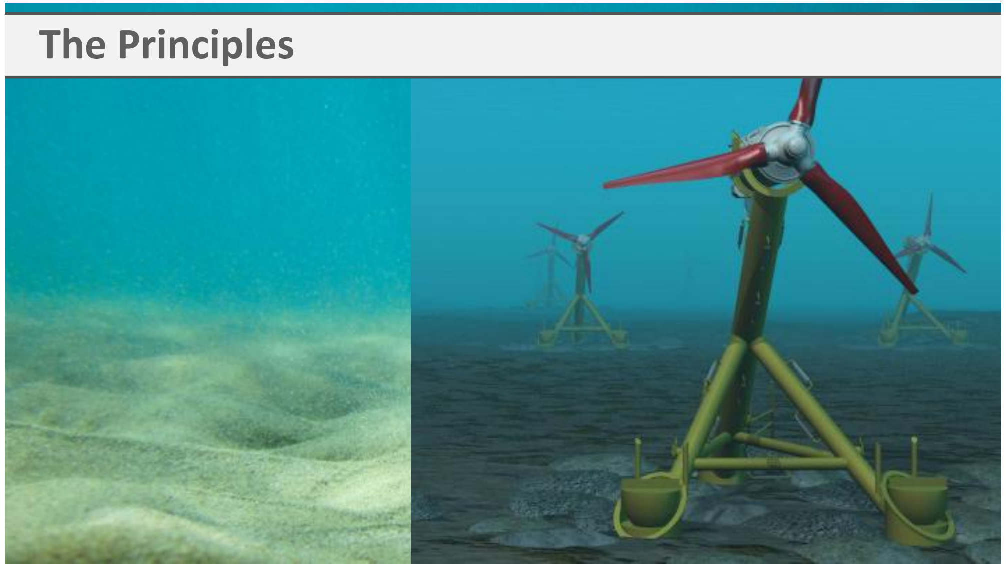
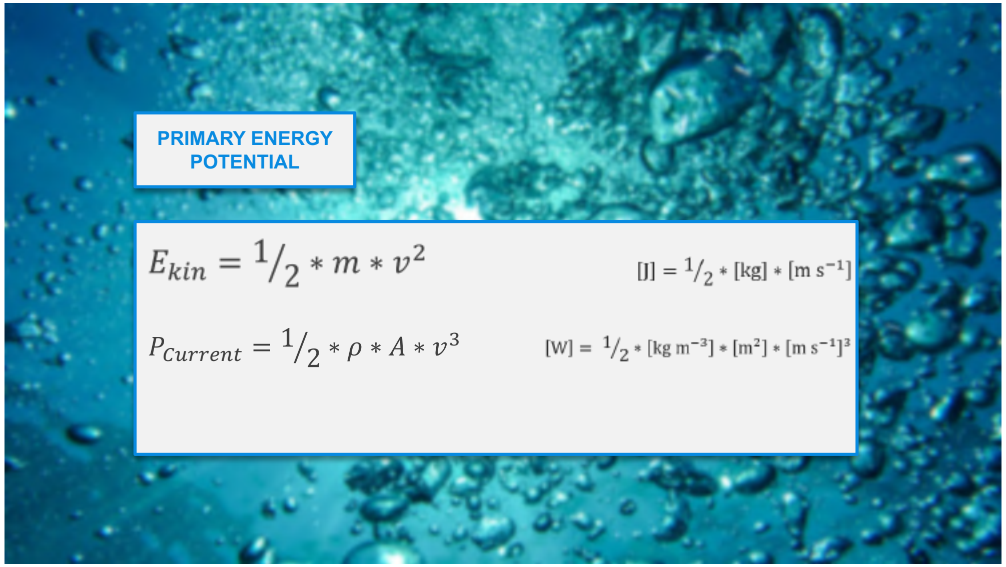

Renewable energy generation
Ocean Current & Wave energy
Professor Arno Smets


The Principles


PRIMARY ENERGY POTENTIAL
$E_{kin} = {}^{1}/_{2} * m * v^{2}$
$[J] = {}^{1}/_{2} * [kg] * [m\ s^{-1}]$
$P_{Current} = {}^{1}/_{2} * \rho * A * v^{3}$
$[W] = {}^{1}/_{2} * [kg\ m^{-3}] * [m^{2}] * [m\ s^{-1}]^{3}$

SYSTEM EFFICIENCIES

$$Cp = \frac{Electricity\ produced\ by\ the\ turbine}{Total\ Energy\ Available\ in\ the\ Wind}$$

ENERGY YIELD

Seasonal Variations

Movement of Tectonic Plates

Large Storms

Calculation Example

Given Information

$D = 20\ [\mathrm{m}]\ \&\ v = 1.5\ [\mathrm{m\ s^{-1}}]\ \&\ C_p = 0.3\ \&\ \rho = 1025\ [\mathrm{kg\ m^{-3}}]$

Gather Values

$A = \pi * \left({}^{1}/_{2} * 20\right)^2 = 314\ [\mathrm{m^2}]$

Calculate Potential

$P_{Current} = {}^{1}/_{2} * 1025\ [kg\ m^{-3}] * 314\ [m^2] * 1.5^3\ [m\ s^{-1}]^3 * 0.3 = 163\ [\mathrm{kW}]$

ADVANTAGES

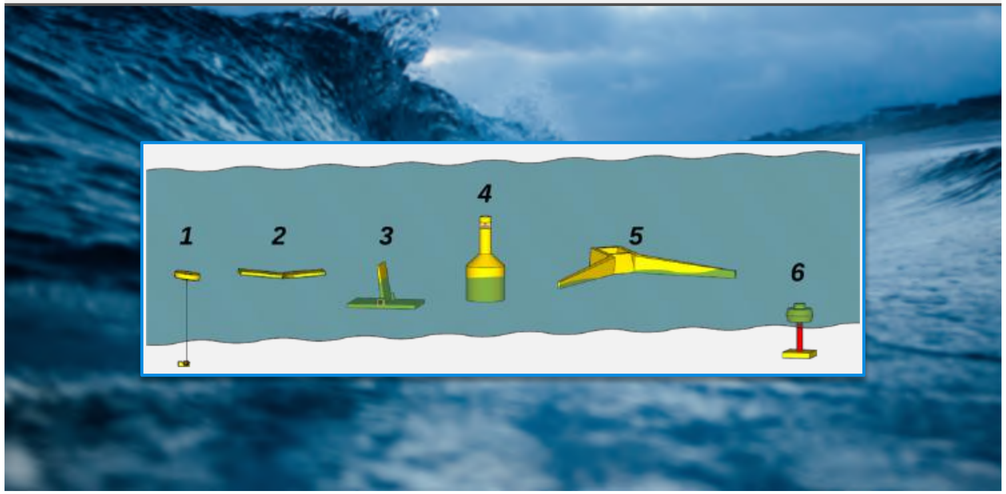
- Continuous
- Ocean Current contains more energy than wind

CHALLENGES

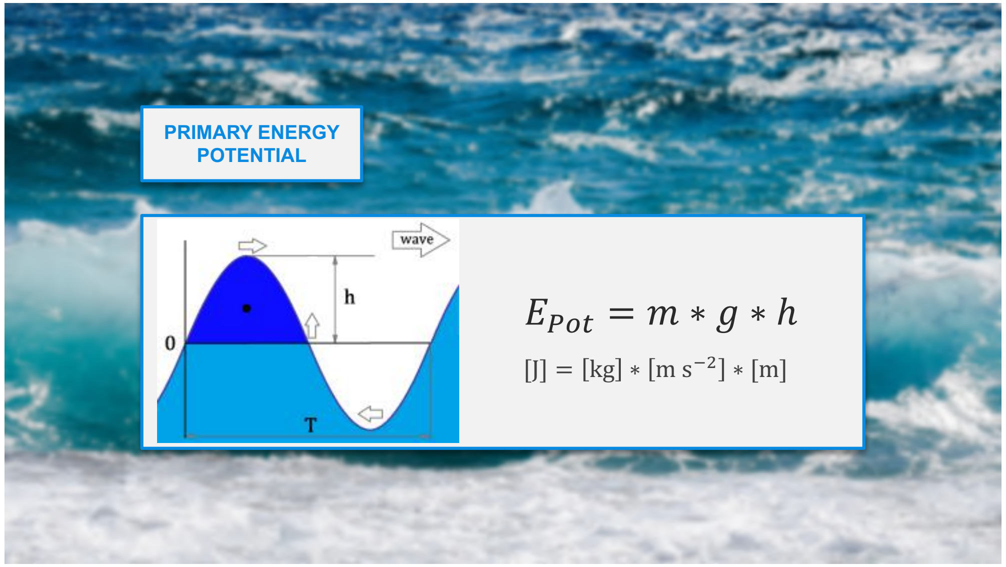
- Corrosion
- Reliability Issues
- Algae Growth
- Impact Marine Life

The Principles

The Principles



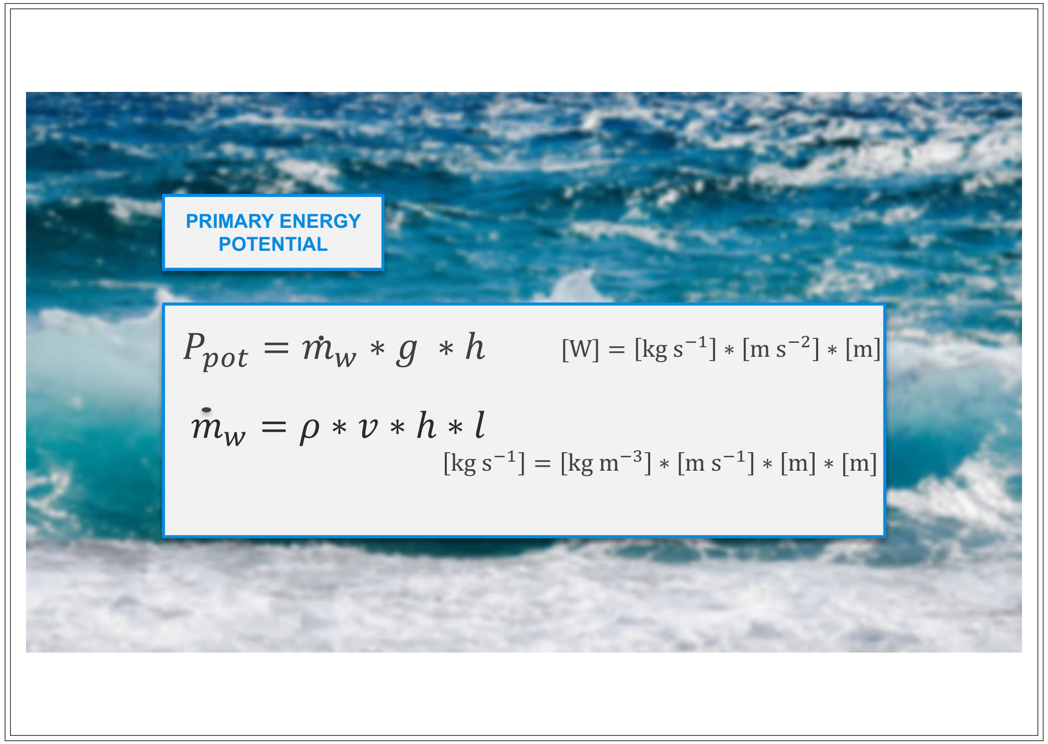
The Principles

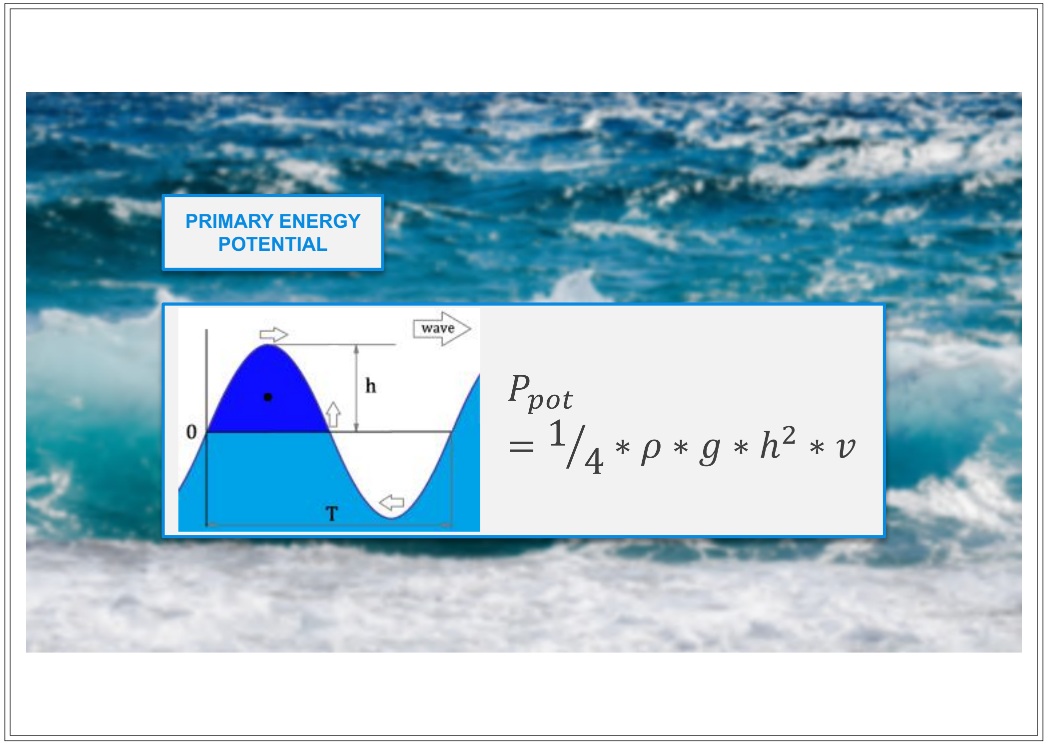


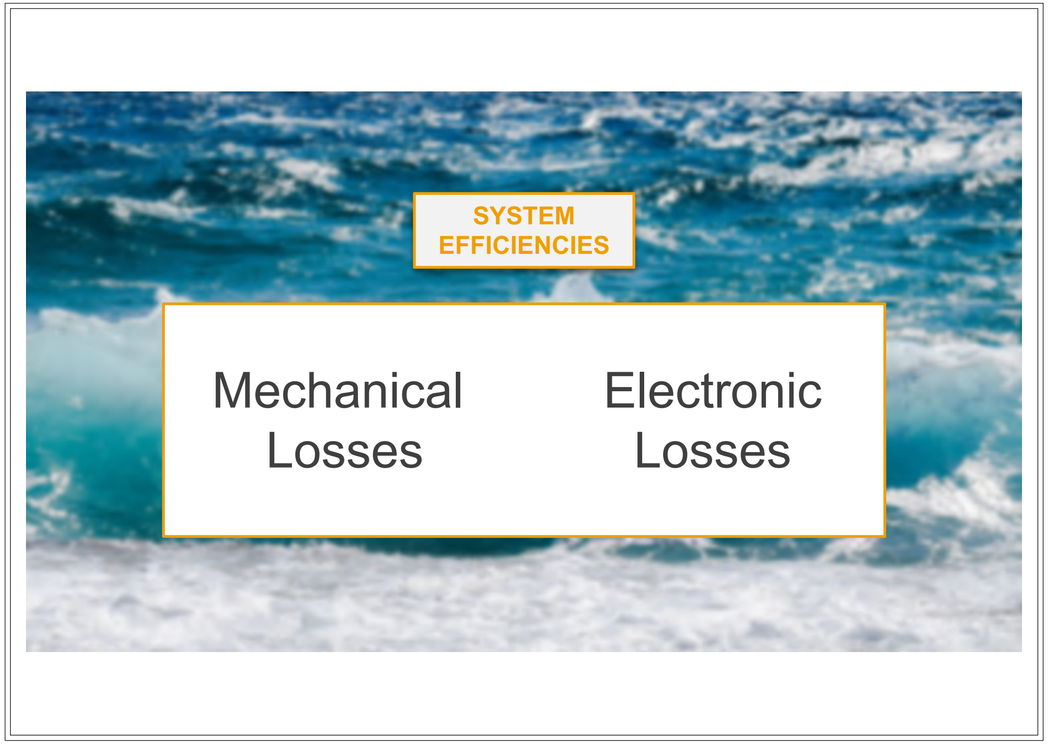
PRIMARY ENERGY POTENTIAL

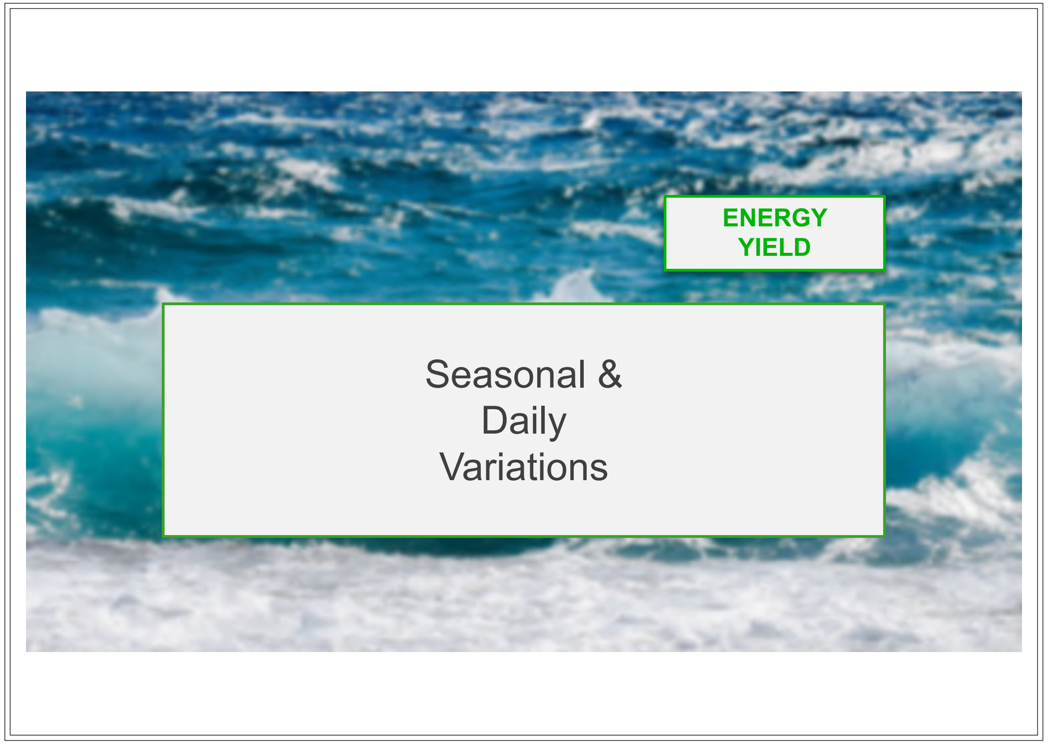
$$E_{Pot} = m * g * h$$

$$[\mathrm{J}] = [\mathrm{kg}] * [\mathrm{m\ s^{-2}}] * [\mathrm{m}]$$


PRIMARY ENERGY POTENTIAL
$P_{pot} = \dot{m}_w * g * h$
$[\mathrm{W}] = [\mathrm{kg\,s^{-1}}] * [\mathrm{m\,s^{-2}}] * [\mathrm{m}]$
$\dot{m}_w = \rho * v * h * l$
$[\mathrm{kg\,s^{-1}}] = [\mathrm{kg\,m^{-3}}] * [\mathrm{m\,s^{-1}}] * [\mathrm{m}] * [\mathrm{m}]$

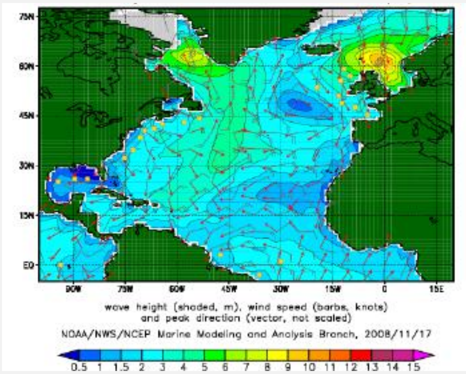

PRIMARY ENERGY POTENTIAL
wave
h
0
T
$P_{pot} = {}^{1}/_{4} * \rho * g * h^2 * v$


SYSTEM EFFICIENCIES
Mechanical Losses
Electronic Losses


ENERGY YIELD
Seasonal & Daily Variations

Calculation Example

Given Information



$$v = 11\ [\mathrm{m\ s^{-1}}]$$

$$h = 5\ [\mathrm{m}]$$

Calculation Example

Given Information

$v = 11\ [\mathrm{m\ s^{-1}}]$ & $h = 5\ [\mathrm{m}]$

Gather Useful Values

$\rho = 1025\ [\mathrm{kg\ m^{-3}}]$ $\quad g = 9.81\ [\mathrm{m\ s^{-2}}]$

Calculate Potential

$$P_{pot} = {}^{1}/_{4} * 1025\ [\mathrm{kg\ m^{-3}}] * 9.81[\mathrm{m\ s^{-2}}] * 5^2[\mathrm{m}]^2 * 11[\mathrm{m\ s^{-1}}] = 691\ [\mathrm{kW\ m^{-1}}]$$

ADVANTAGES

- Predictable character
- Low operational costs

CHALLENGES

- High investment costs
- Environmental impact
- Obstruction of sea travel
- Unavailability of suitable locations

Global Perspective

Given Information

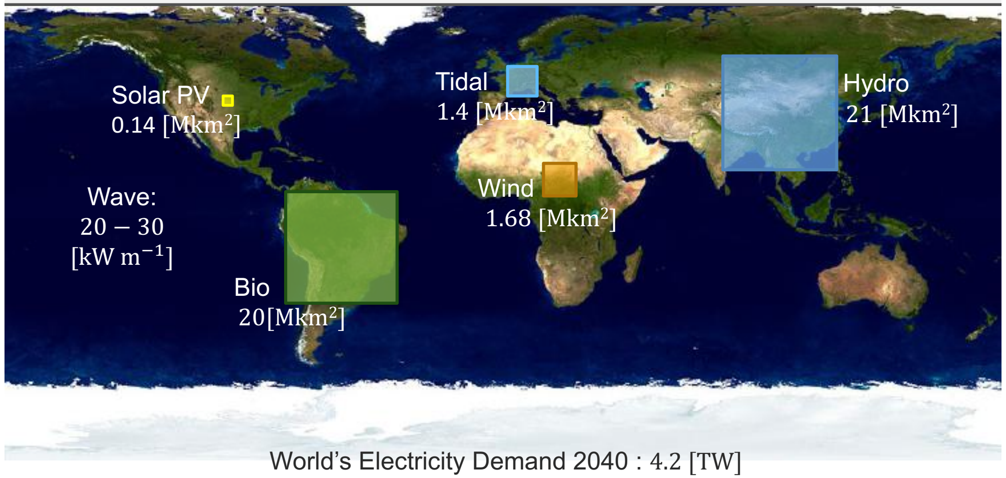
Global Energy Yield= $3.37\ [\mathrm{GWh\ year^{-1}}]$ Global Population= $7.5 * 10^9 [\mathrm{person}]$

Other Units

$$E_{GlobalYield} = 3.37\ [\mathrm{GWh\ year^{-1}}] * {}^{1}/_{7.5\ *\ 10^9}\ [\mathrm{person^{-1}}] * {}^{1}/_{365}\ [\mathrm{year\ day^{-1}}]$$

$$E_{GlobalYield} = 0.45\ [\mathrm{Wh\ person^{-1} day^{-1}}]$$

Global Perspective



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Thank you for your attention!