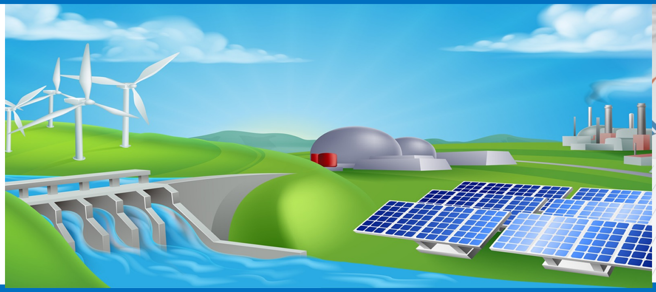



# ECONOMICS OF MODERN POWER SYSTEMS

## M3 – Distributed Generation

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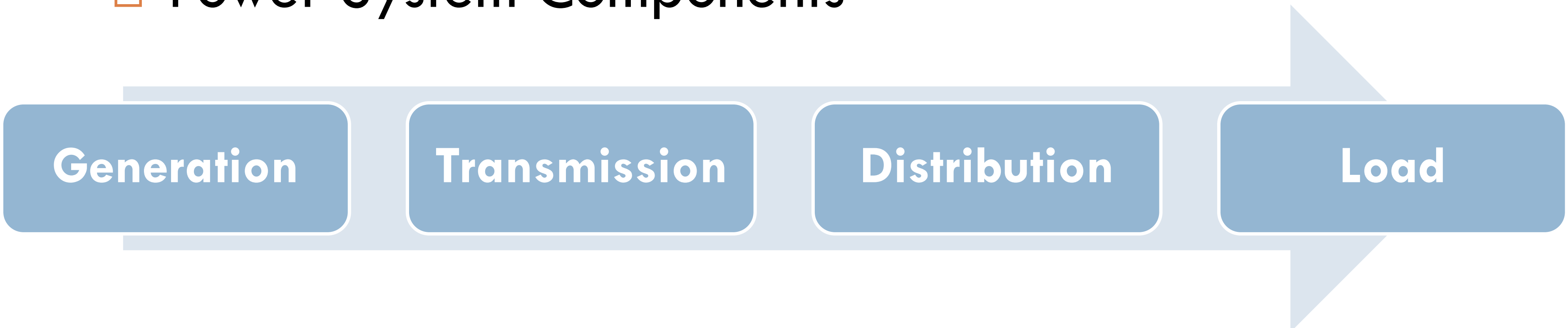
# Learning Goals

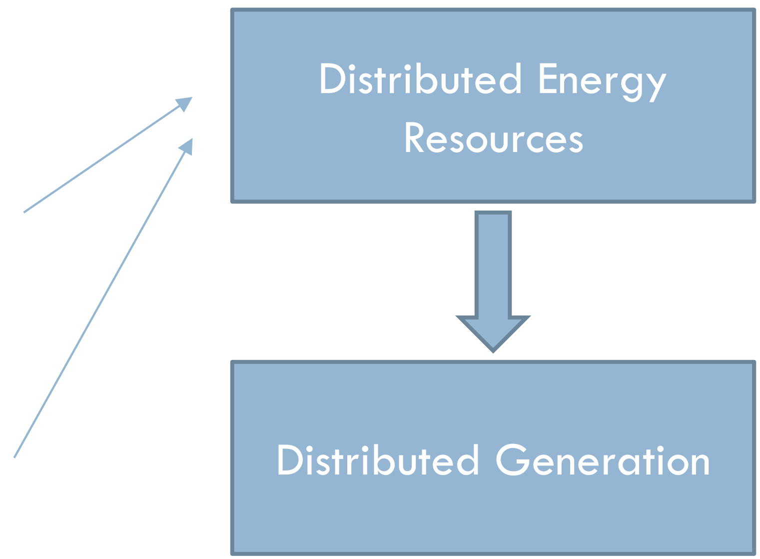
- More on DG
  - History
  - Common technologies
  - Interconnection
- PV study case
  - Show how to use SAM

# So far…

- Power System Components



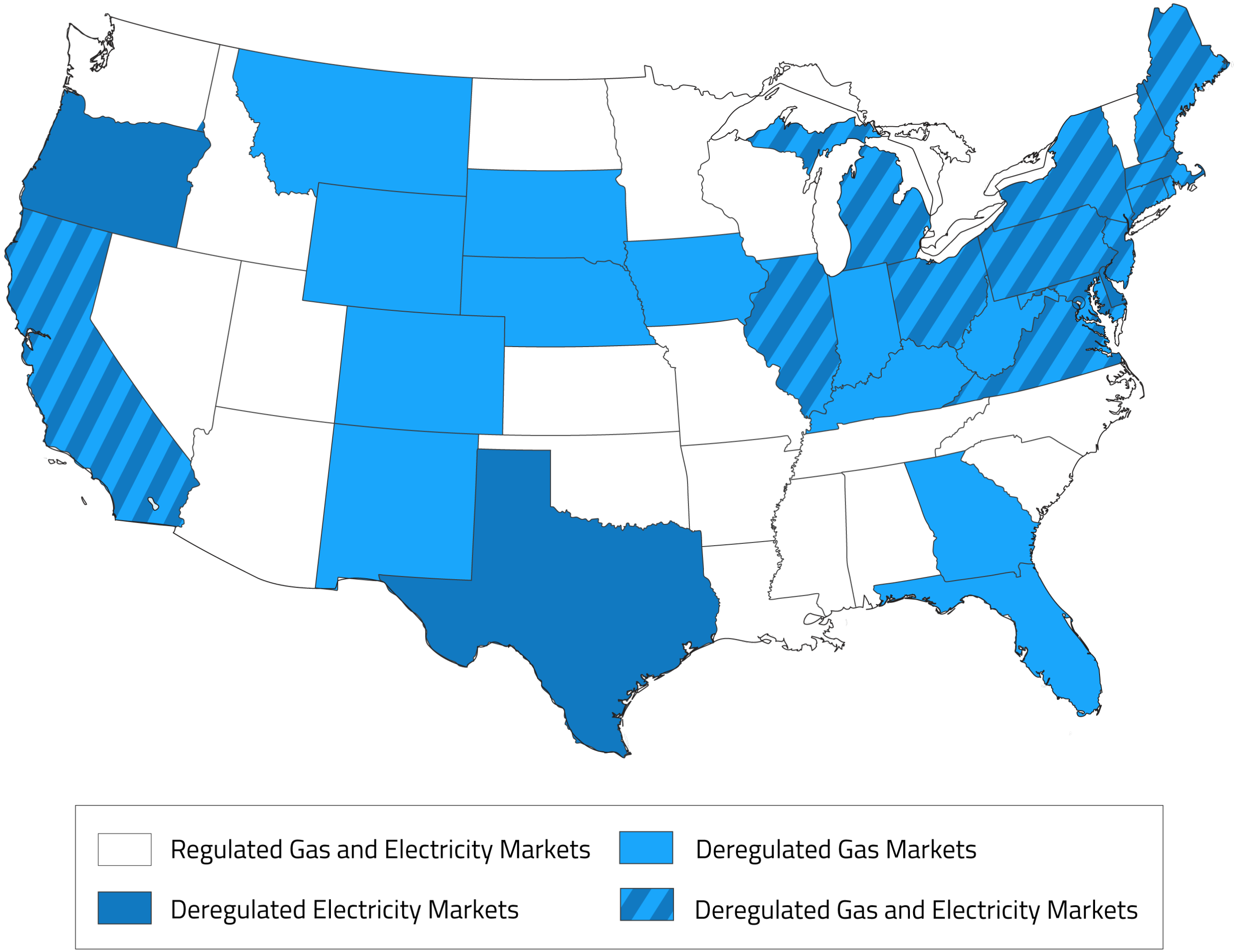

- Old Grids and Smart Grid
- How Distribution will change
- How Generation will change



# History of DG

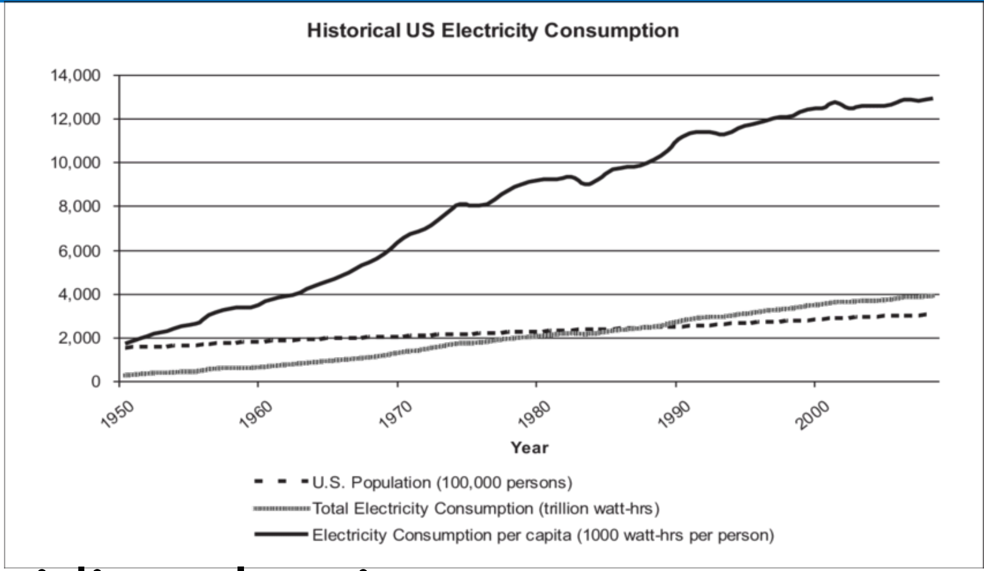
- Started with Public Utility Regulatory Policies Act (PURPA) of 1978
  - Creation of new technologies
  - Spurred research on environmentally preferable technologies that used water, wind, or solar power to produce electricity
  - Challenged the control held by power company managers
  - Began the process of deregulation of electricity sector **(generation, transmission, distribution and marketing)**

# Map of Deregulated Energy Markets



# Motivation for DG

- Economically viable
  - Less time to build
  - Put less capital at risk
  - Match the growth
  rate of consumption (~3%)




- Improve efficiency of providing electric power
  - Electricity transmission from power plant to user wastes from 4-9% of electricity

*DG can provide customers affordable power at a higher level of quality*

# Types of DG technologies

- Distributed generators come in three types
  - ***Induction (or asynchronous) generators***

    *Ex: wind turbines and Combined Heat and Power (CHP)*
  - ***Synchronous generators***

    *Ex: thermal power*
  - ***Inverters***

    *Ex: solar PV*

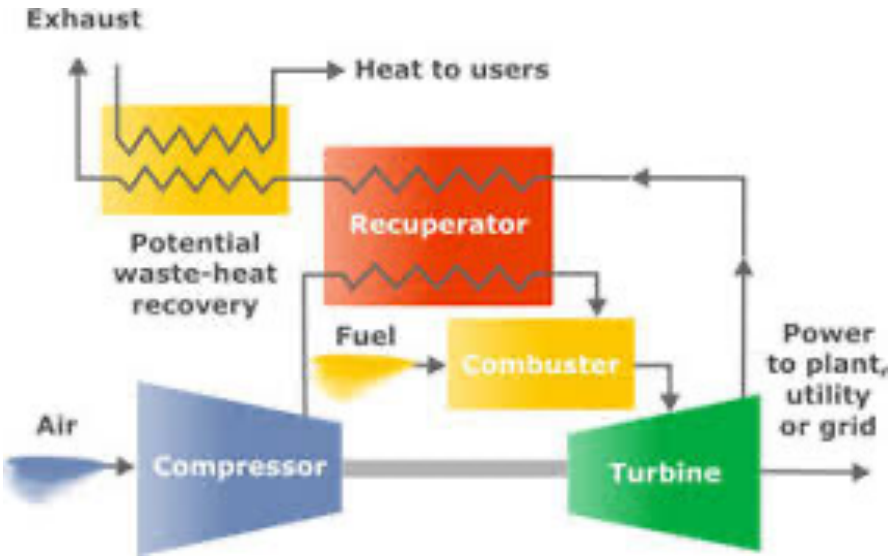
Table 1. Typical available size per module for DG

| Technology | Typical available size per power module |
|---|---|
| Combined Cycle Gas Turbine | 35 - 400 MW |
| Internal Combustion Engines | 5 kW - 10 MW |
| Combustion Turbine | 1 - 250 MW |
| Micro-Turbines | 35 kW - 1 MW |
| Fuel Cells, Phos.Acid | 200 kW - 2 MW |
| Fuel Cells, Molten Carbonate | 250 kW - 2 MW |
| Fuel Cells, Proton Exchange | 1 - 250 kW |
| Fuel Cells, Solid Oxide | 250 kW - 5 MW |
| Battery Storage | 500 kW - 5 MW |
| Small Hydro | 1 - 100 MW |
| Micro Hydro | 25 kW - 1 MW |
| Wind Turbine | 200 W - 3 MW |
| Photovoltaic Arrays (PV Arrays) | 20 W - 100 kW |
| Solar Thermal, Central Receiver | 1 - 10 MW |
| Solar Thermal, Lutz System | 10 - 80 MW |
| Biomass Gasification | 100 kW - 20 MW |
| Geothermal | 5 - 100 MW |
| Ocean Energy | 100 kW - 5 MW |

*Source: Dulau et al, "Distributed generation technologies and optimization"*

# Cogeneration Technologies

- Distributed generation resource – simultaneous production of heat and electricity
- Permit business to reuse thermal energy that would normally be wasted
  - E.g. Iron and steel, chemical processing, refining, paper manufacturing



# Islanded x Interconnected DG

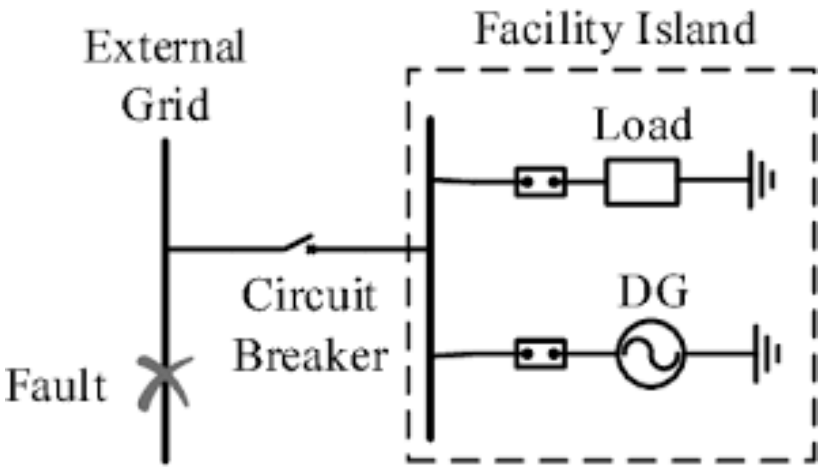
- Islanded DG
  - Small generator connected directly to the load and serving that load only
  - Reduce load placed on distribution grid at the discretion of the owner
  - May increase volatility of the load
- Interconnected DG
  - Connected to distribution grid in addition to a particular load
  - Can cause power to flow in opposite direction
    - Safety and reliability concerns

# Why install a grid-connected system?

- Assurance of receiving power from the utility when your system is not producing as much power as you need
- Essential for renewable technologies like solar and wind
- Potential benefit: ability to sell power back to the utility
- Net metering (might have a cap)
- Larger generators may stablish power purchase agreements (PPA)
- Off-grid systems make sense for sites far from existing utilities lines

# “Intentional” Islanding

- Purposeful sectionalization of the utility system during widespread disturbances to create power “islands”
- The islands can maintain continuous supply of power during disturbances of the main grid



# Interconnection Process

- DG system owner ***must*** obtain written approval from the local utility in the form of an Interconnection Service Agreement and subsequent Authorization to Connect
  - Note: emergency generators are not required to follow this process
- Utility should review your project to make sure there are no negative impacts on the grid
- You may need to incorporate new equipment to protect the reliability and safety of the grid
  - Usually not necessary for small renewable generators

# Interconnection Studies

- Power Flow Analysis
- Voltage Analysis
- Short Circuit Analysis
  - determine the magnitude of the currents that flow during an electrical fault
  - Compare values with equipment ratings

*Analysis should consider different scenarios for generation and load to account for intermittency and load variability*

# Rooftop PV Investment Analysis

Study Case

# Background

- Solar PVs is the dominant type of distributed renewable energy system
- What's the viability of such an investment for a residential consumer?
- Two components drive the return from PV system
  - Total amount of electricity produced
  - Net value of that production
- Value of PVs is given by number of kWh produced and how much they are worth

# Decision process

A PV investment analysis is divided in five steps:

1. Estimating System Production
2. Assessing System Cost
3. Forecasting the Value of Electricity
4. Understanding Incentives
5. Conducting a Financial Analysis

# 1- Estimating System Production

- Site specific solar factors are critical
  1. Shading
     - has the most visible negative impact of production
     - vary by season as the sun angle becomes lower in winter
  2. Position
     - Panels facing east or west will produce less than same installation facing south
  3. Tilt or roof slope
     - Flatter angles increase production in summer but decrease in winter

# 1- Estimating System Production

4. Temperature
   - Increased temperature increase electrical resistance and consequently reduces efficiency

- Side note: PV panels come with 25 years warranty, but sun degrade PV
  - Production will decline around 0.5% a year
  - i.e., after 25-years, you only have 87,5% of original installed capacity

# 2- Assessing System Cost

- Direct Capital Costs
  - Panel modules, inverter, hardware
- Indirect Capital Costs or soft cost
  - Installation (most of it), grid interconnection, engineering, permitting, environmental studies and sales tax
- Operation and Maintenance
  - Annual expenses to maintain, service and replace components
  - Usually around $19 per kW/year for midsize

# 3- Forecasting the Value of Electricity

- No standardized electricity rate structure
- Typical charges
  - Fixed monthly charge
    - Associated with infrastructure cost
    - PV system will not reduce that!
  - Energy charge
    - Covers the cost of producing energy (kWh)
    - PV install will reduce that
  - Demand charge
    - Covering peak demand requires power plant to provide energy for relatively short durations
    - PV may reduce this fee but often PV does not align with peak demand charges

# 3- Forecasting the Value of Electricity

- The higher the electricity rate, the greater will be the value of PVs
- Important to consider electricity price increase
  - Usually escalation rates range from 0.5 to 3%
  - Use your beliefs, e.g, if you think environmental concerns might increase prices, use a higher value

# 4- Understanding Incentives

- Four primary sources of incentive: federal, state, local governments and utility
- Why the incentive?
  - Renewable energy and energy efficiency merit financial support
  - Other reasons
    - Federal: Growth of energy independence and environmental responsibility
    - State & utility: reducing energy costs and demand
- Incentives target specific sectors

# 4- Understanding Incentives

- Key residential incentives
  - Residential Renewable Energy Tax Credit (RRETC) (30%)
  - Net metering policies
    - Credit for excess generation
    - Usually one year cycle
    - Different compensation rates for net excess generation
- Sale of Solar Renewable Energy Credit can generate income for PVs system owners
  - Offset installation cost
  - How do you negotiate it?
    - Owner may entry into an SREC agreement with a broker, or
    - Sell the SRECs to the system developers (some investors simplify by calling it a discount, rebate or refund

# 5- Conducting Financial Analysis

- Financial Return
- Payback: number of years for the energy savings from PV to offset initial cost

$$Payback[yr] = \frac{InitialCost(\$)}{AnnualProduction\left(\frac{kWh}{yr}\right) x\ Value\left(\frac{\$}{kWh}\right) - O\&M\left(\frac{\$}{yr}\right)}$$

- Check if payback is smaller than lifetime of the project
- Problem: too simple for this type of analysis
- Ignores energy price escalation, variable rate electricity pricing, time value of the money, etc

# 5- Conducting Financial Analysis

- Levelized cost of electricity (LCOE) expresses the cost of electricity produced from a PV system
- LCOE closely related to Net Present Value
  - Includes construction and operation cost
- LCOE can be use to compare different electricity sources

# Final Remarks

- PV system owners should revise their homeowner policy to include cost of replacement of a PV system in the event of a natural disaster
- When making your decision don't look at the cost alone, think about
  - How much do you value energy independence?
  - How much do you value clean energy?

# Let's take a look at SAM

System Advisor Model (SAM) from NREL

# Overview of the Model

- SAM is an open source project !!
- SAM simulates the performance of
  - photovoltaic with optional storage
  - concentrating solar power
  - solar water heating
  - wind
  - geothermal, and
  - biomass power systems
- Also includes a basic generic model for comparisons with conventional or other types of systems

# Overview of the Model

- Does not model off-grid power system with more than one power generator
  - **H**ybrid **O**ptimization of **M**ultiple **E**nergy **R**esources (HOMER) could be an option for that
- Desktop application comes with a set of libraries
  - Module parameter
  - Inverter parameters
  - Solar hot water collector
  - Wind turbine power curves, etc

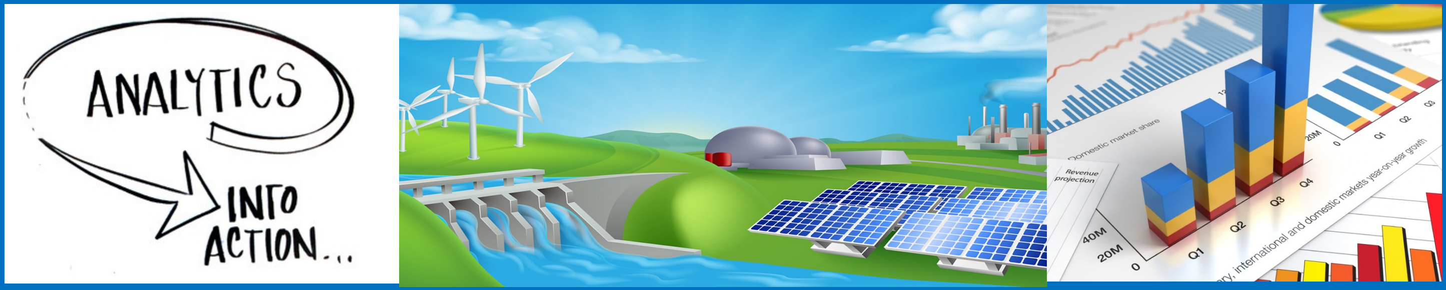
# Overview of the Model - Inputs

- SAM can automatically download data from
  - OpenEU utility rate database
  - NREL National Solar Radiation Database
  - NREL Wind Integration Datasets
  - NREL Biofuels Atkas and DOE Billion-Ton Update (biomass supply)
- Examples of input variable
  - Installation cost, labor, land, O&M
  - Number of modules and inverter
  - Analysis period, discount rate, inflation, tax, power purchase price (utility financing models)
  - Tax and cash incentive

**SAM comes with default values for most of these parameters**

# Overview of the Model

- Performance Models for
  - PVs, CSP, Wind, Solar Water Heating, Biomass Power
- Financial Models
  - Residential and commercial
  - Power generation (PPAs)
  - LCOE calculator
- E.g. for residential projects, SAM report will be
  - LCOE
  - Electricity cost with and without the renewable system
  - Electricity saving
  - After-tax net present value
  - Payback period




# THANK YOU !

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