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Nuclear-renewable hybrid energy systems for non-electric applications

Cost issues

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Outline

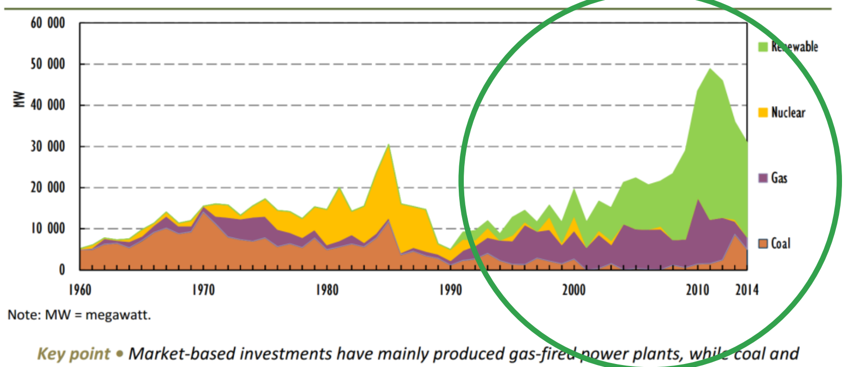
- System effects due to the introduction of *Variable Renewable Energies* (VREs)
- Costs related to the integration of VREs into existing grids
- Nuclear + VREs for non-electric applications
- A basis for comparing the costs of different options available

System effects due to the introduction of *Variable Renewable Energies* (VREs)

System effects due to the introduction of *Variable Renewable Energies* (VREs)

- Power plants are not isolated. They are physically – and economically – *interacting* with each other.
- Interactions result in *system effects*.
- System effects are becoming increasingly important due to the introduction of *Variable Renewable Energies* (VREs).

Figure 1.3 • Capacity addition in OECD Europe by technology, 1960-2014



Note: MW = megawatt.

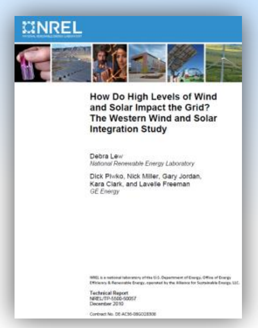
Key point • Market-based investments have mainly produced gas-fired power plants, while coal and nuclear have been built under a regulated framework, and renewables have been installed with support schemes.

Renewable electricity variability issues

- VREs have two characteristics potentially affecting *grid-level system costs*:
  - They are located in areas with favorable meteorological conditions, often far from urban and industrial load centers.
    - ➢ Extension of electricity distribution and transport grids.
  - They have a variable output, impacting other power plants within the grid system.
    - ➢ Dispatchable generation technologies (fossil- and nuclear-type, hydro) need to be maintained to ensure security of supply. They will be operating at reduced load factors.

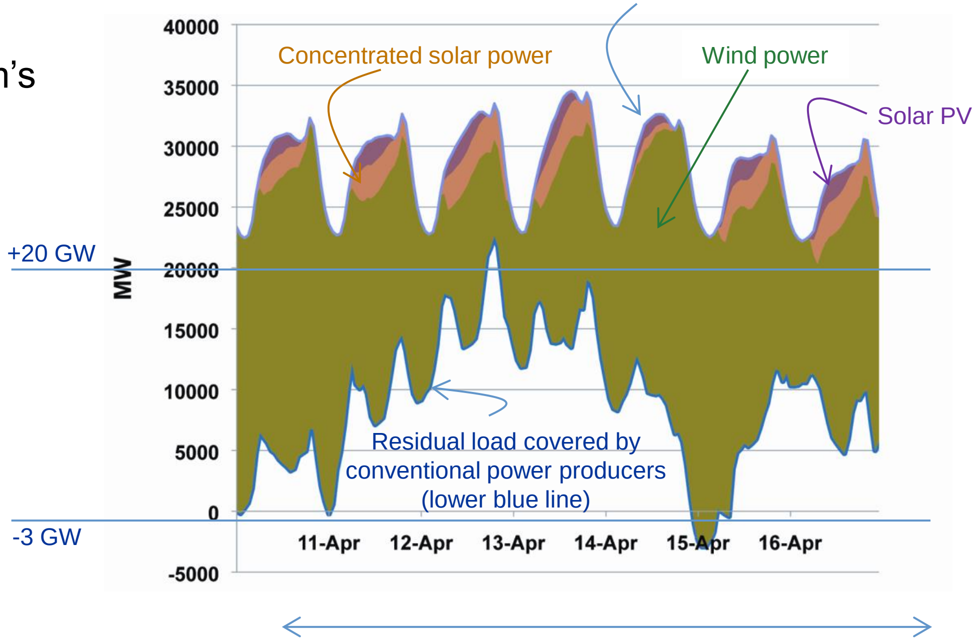
Renewable electricity variability issues

- Fluctuations in renewable power output
  - Small, swift fluctuations (seconds to minutes)
  - Slow variations (minutes to hours)
    - Could affect the power system's stable operation
- How variability issues are addressed?
  - Important factors:
    - Grid capacity
    - Share of renewable electricity
  - Strategies:
    - More reserve capacity
      - % of the installed variable capacity
    - More interconnection



Impact of a 35% share of renewable energy in the WestConnect area in the Western part of the US

Illustration: NREL*



(most volatile meteorological conditions of the past three years)

* How Do High Levels of Wind and Solar Impact the Grid? The Western Wind and Solar Integration Study, Technical Report, NREL/TP-5500-50057, December 2010

Costs related to the integration of variable renewables into existing grids

System costs

System costs are the total costs above plant-level costs to supply electricity at a given load and given level of security of supply

Total system costs

Costs and benefits of integrating new capacity

Other externalities: environmental, security of supply, cost of accidents, etc.

Impact on other electricity producers

Reduced prices and load factors of conventional plants in the short-run

Re-configuration of the electricity system in the long-run

Grid-level system effects

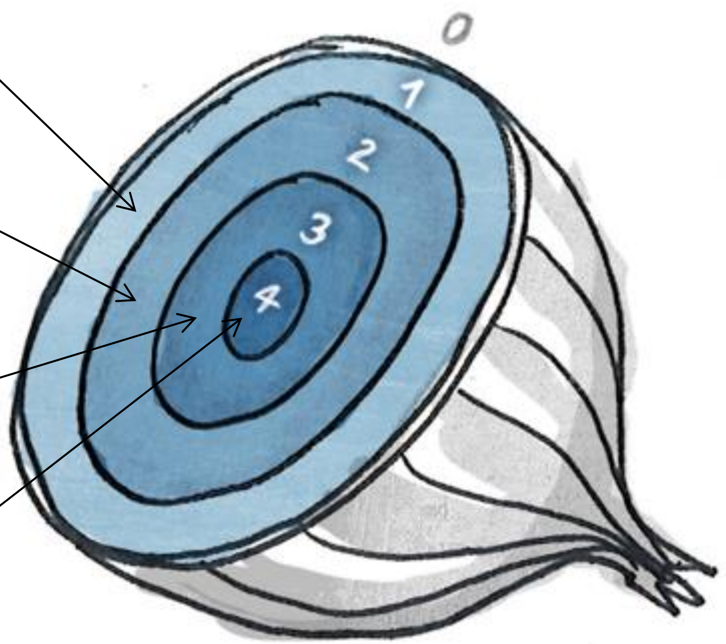
Grid connection

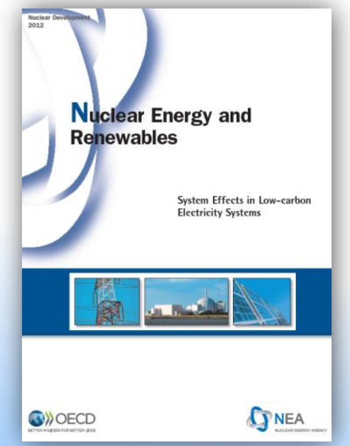
Grid-extension and reinforcement

Short-term balancing costs

Long-term costs for maintaining adequate back-up capacity

Plant-level costs





Costs related to the integration of variable renewables into existing grids

- Two types of costs attached to the integration of renewables into existing grids:

1. Grid connection and upgrading costs
   - Grid connection costs (IRENA, 2012)
     May be significant depending on geographic location of energy sources.
     ~ 5% of the investment cost for most technologies
     ~ 11-14 % for onshore wind farms
     ~ 15-30 % for offshore wind farms
   - Grid upgrading costs (IRENA, 2015)
     ~ 0.5-3.0 Euro per MWh for a 20%-30% renewable (wind) electricity share

2. System operation costs
   - Higher penetration of renewables → reduced plant utilization of conventional power generation system
     - Range (IRENA, 2015): ~ 15-25 Euro per MWh (depending on the electricity share)

Short-run impacts

Impacts of the deployment of variable renewables on the load factors and profitability of dispatchable technologies in the short run

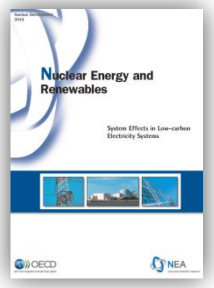
Nuclear Energy and Renewables: System Effects in Low-carbon Electricity Systems
OECD 2012

Renewables with zero marginal costs

▼ Electricity produced by dispatchable power plants
▼ Electricity price on wholesale power markets

▼ Profitability of dispatchable power plants

▼ Economical incentives to built new power plants
▲ Security of supply risks



NPP are capital-intensive plants with an operation cost almost independent from the amount of electricity generated

Penetration level		10%		30%	
Technology		Wind	Solar	Wind	Solar
Load losses	Gas turbine (OCGT)	-54%	-40%	-87%	-51%
	Gas turbine (CCGT)	-34%	-26%	-71%	-43%
	Coal	-27%	-28%	-62%	-44%
	Nuclear	-4%	-5%	-20%	-23%
Profitability losses	Gas turbine (OCGT)	-54%	-40%	-87%	-51%
	Gas turbine (CCGT)	-42%	-31%	-79%	-46%
	Coal	-35%	-30%	-69%	-46%
	Nuclear	-24%	-23%	-55%	-39%
Electricity price variation		-14%	-13%	-33%	-23%

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Nuclear + renewables for non-electric applications

Flexibility options

- The continuous matching of demand and supply could be achieved by:
  - Demand side management
  - Grid interconnections and market integration
  - Dispatchable back-up capacity
  - Load following
  - Energy storage
  - Coupling with external processes

Load following

- NPPs load following capabilities (as demonstrated in France and in Germany) are comparable to those of coal-fired power plants.

	Start-up time	Maximal change in 30 sec	Maximum ramp rate (%/min)
Open cycle gas turbine (OCGT)	10-20 min	20-30%	20%/min
Combined cycle gas turbine (CCGT)	30-60 min	10-20%	5-10%/min
Coal plant	1-10 hours	5-10%	1-5%/min
Nuclear power plant	2 hours - 2 days	up to 5%	1-5%/min

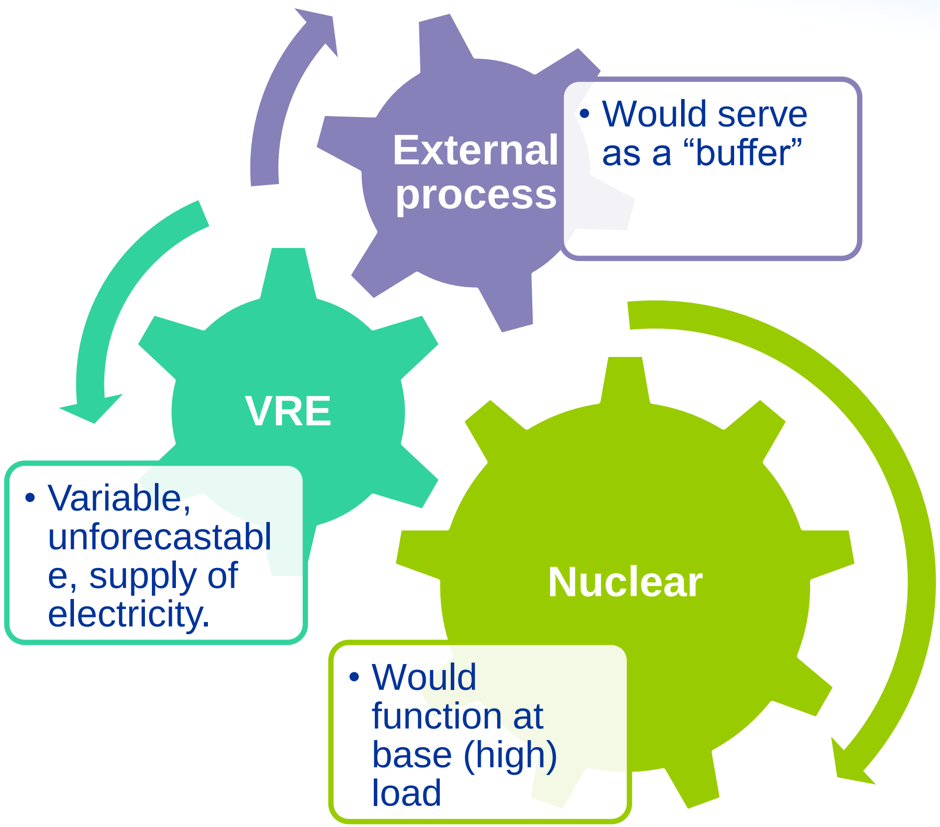
OECD (2012): Nuclear Energy and Renewables, System Effects in Low-carbon Electricity Systems.

- New NPPs can operate at a power level as low as 25% of their rated capacity. Older designs cannot be operated for a prolonged period below 50% of their rated capacity.

- Although technically feasible, operation at reduced load factors affects the overall economics of the nuclear power plants.

Nuclear-renewable hybrid energy systems for non-electric applications

Continuous matching of demand and supply



Coupling with external processes

- The excess electricity / thermal power could be used for non-electric applications.
- This would limit the reduction of load factor due to the introduction of VREs.
- LWRs can be used to produce steam / hot water up to ~ 300 C.
- Steam can be produced by dedicated modules (SMRs) or by turbines operating in cogeneration mode.

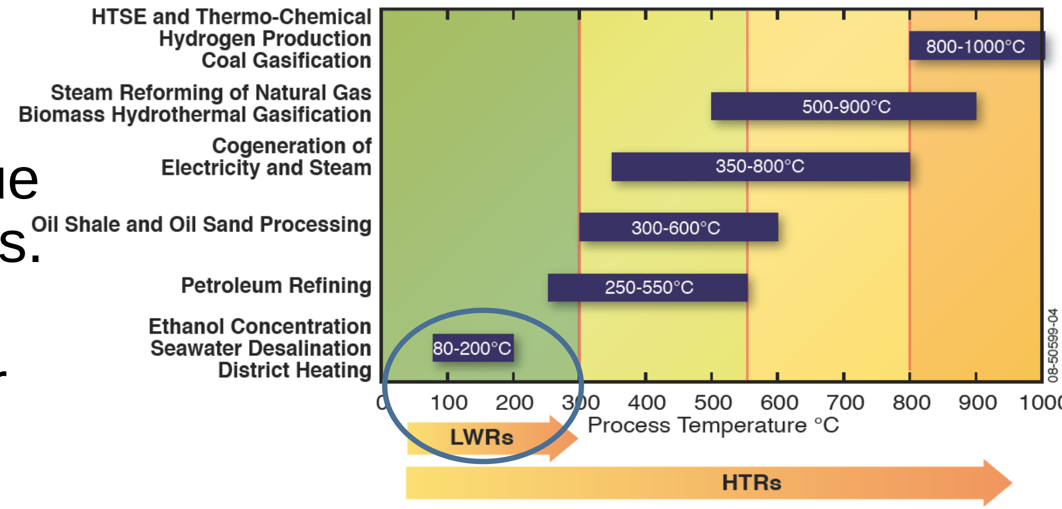
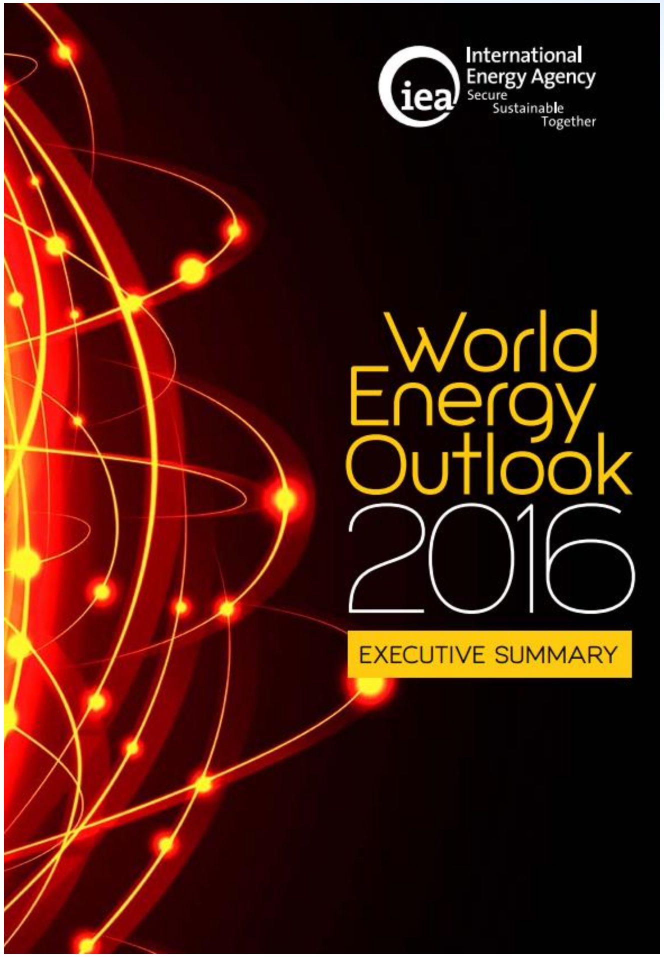


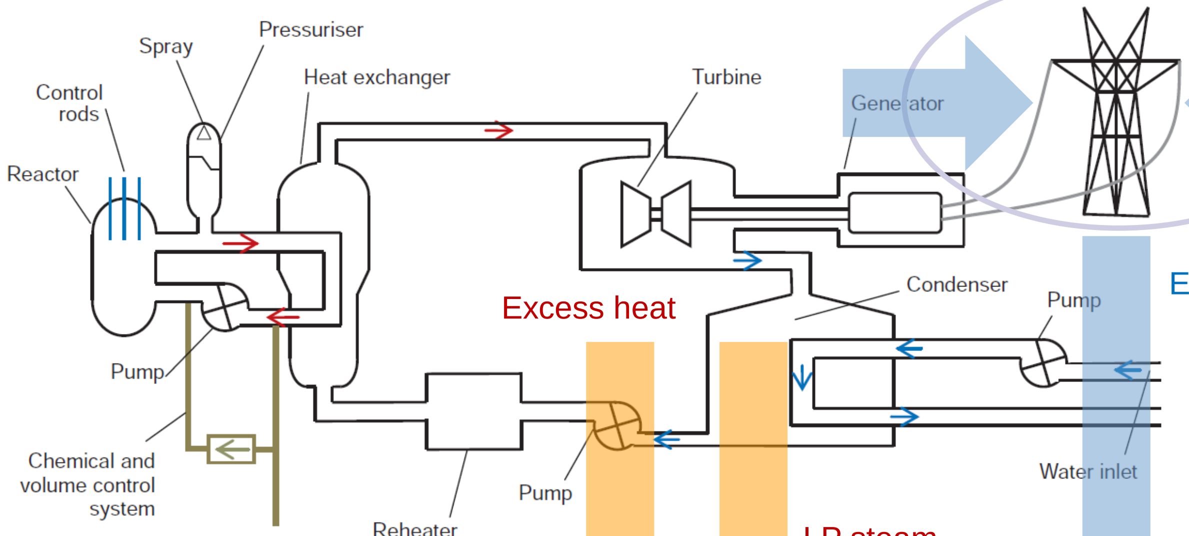
Illustration: NGNP Alliance Blog
http://blog.ngnpalliance.org/2012/06/

- In 2014, some 4% of global electricity consumption was used to extract, distribute and treat water and wastewater, along with 50 million tons of oil equivalent of thermal energy.
- Over the period to 2040, the amount of energy used in the water sector is projected to more than double.
- Desalination capacity rises sharply in [MENA] and demand for wastewater treatment (and higher levels of treatment) grows, especially in emerging economies.
- By 2040, 16% of electricity consumption in the Middle East is related to water supply.



Nuclear-renewable hybrid energy systems for seawater desalination

Grid

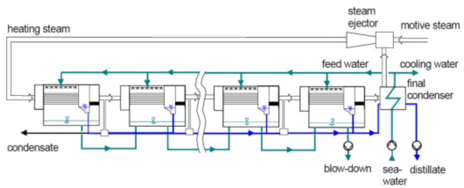


Excess heat

Excess electricity

LP steam

MP steam



Installed capacity ~ 100 10^6 m^3 / day

Energy intensive processes

Thermal Desalination Processes

Seawater Reverse Osmosis

(+)

Hybrid Systems

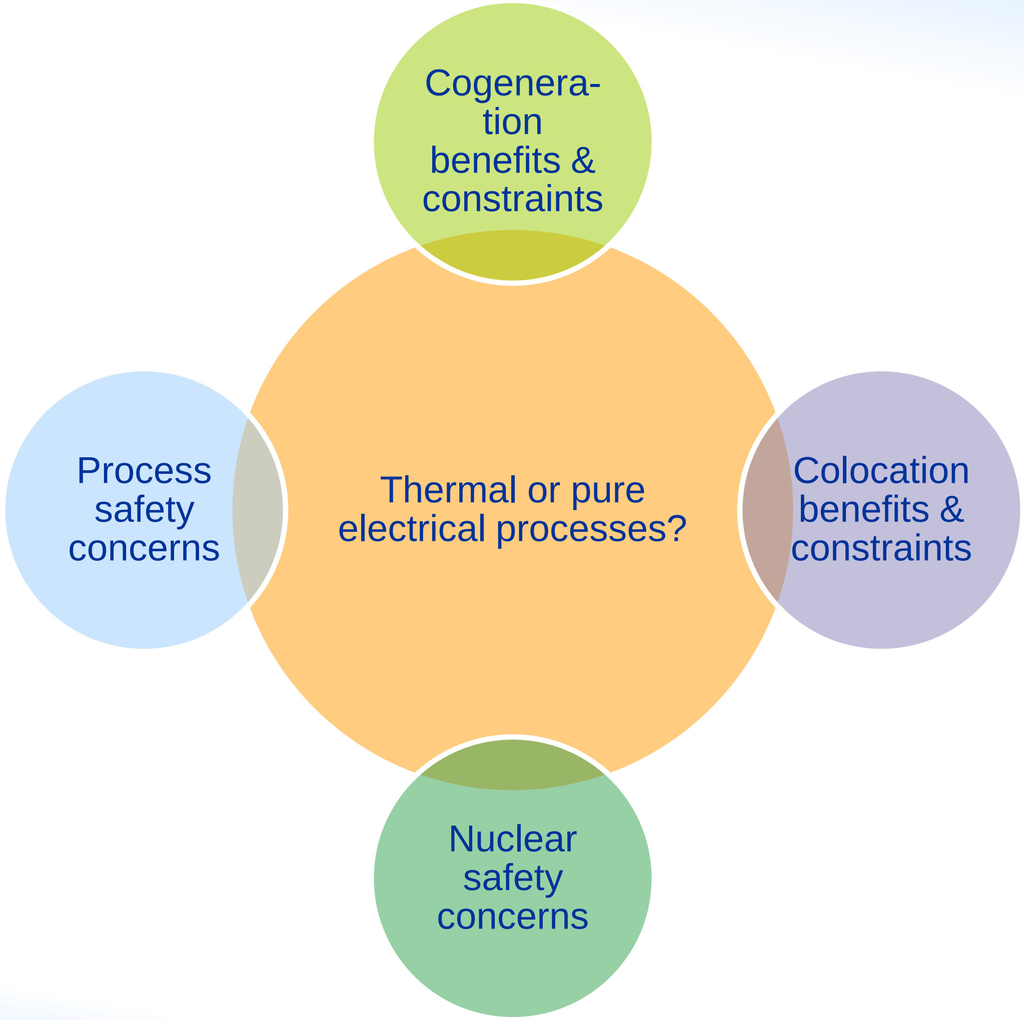
Product water can be stored

Thermal systems (MED) can be fed with two types of steam pressures depending on the load factor of the power plant:

✓ Low pressure (LP) steam (MED), when the demand for electricity is high.

✓ Medium pressure (MP) steam (MED-TVC) or electricity (MED-MVC) when the demand for electricity is low.

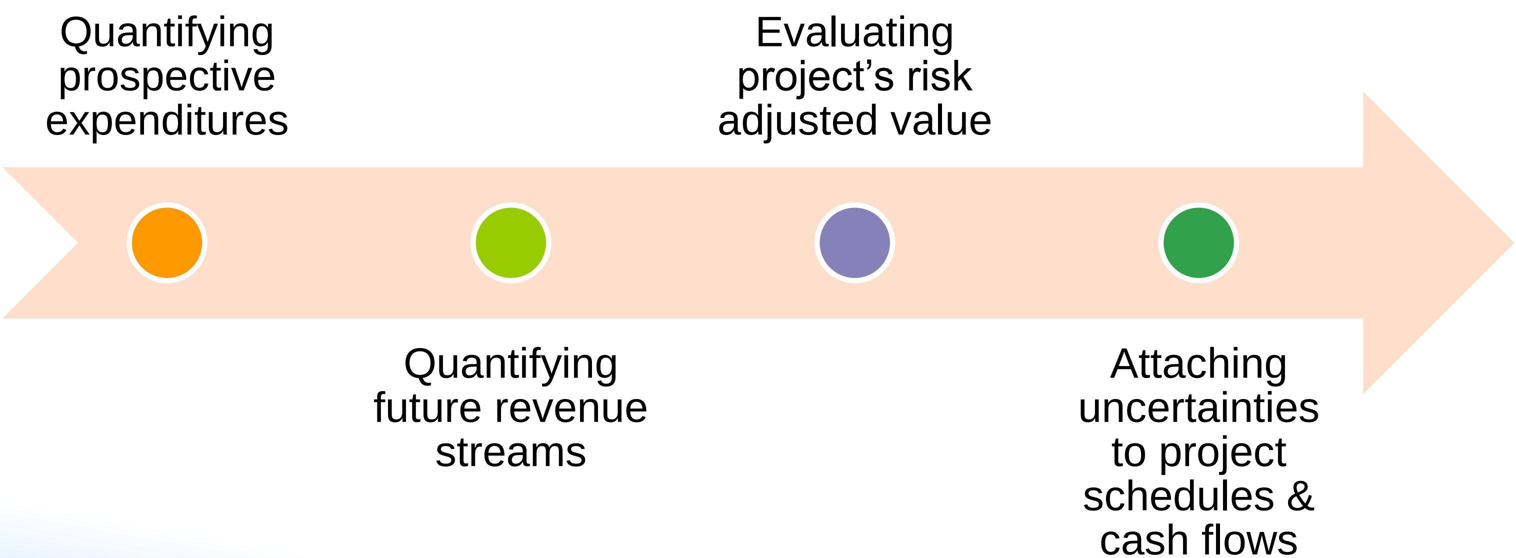
Thermal processes vs. pure electrical systems



A basis for comparing the costs of different options available

Consider the electricity system as a whole: plant-level costs and grid-level costs.

Take into account differences in uncertainty profiles, project schedules and cash in- and out- flows vs. time.



Quantifying prospective expenditures

- Pre-construction and Construction
- Recurring Expenses:
  - Operation and maintenance
  - Provisions for future D&D and radioactive waste disposal activities
- Upgrades and Life Extensions
- Retirement, Decontamination and Decommissioning

Quantifying future revenue streams

- Project ownership and governance aspects,
- Project business model,
- How the project is financed? – How much debt? How much equity? –,
- Shareholder reward policies,
- Accounting system – how Depreciation and Amortization (D&A) and Taxes are taking into account –,
- etc.

Evaluating project's risk adjusted value

- Discounting the expected cash flows using a risk-adjusted discount rate.
- Observing how much the market discounts the value of assets of similar risk.
- Applying probabilistic approaches – Scenario analysis, Decision trees, Monte-Carlo simulations – or two relatively new tools in risk assessment:
  - Value-at-Risk or VaR, focused primarily on dowside risk,
  - Real options, more oriented towards upside risk and its payoff.

Attaching uncertainties to project schedules & cash flows

- Define – and attach uncertainties to – the project's taks' durations and cash flows.
- Propagate these uncertainties through the project's Gantt diagram.
- Determine the distribution of project outcomes.
- Assess the probabilities of project success or failure.
- Rank project's variables taking into account their impact on project outcomes.
- Identify tasks worth tracking during project execution.

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Thank you!