Prospects for nuclear cogeneration, economic assessment methodologies and tools

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IAEA
International Atomic Energy Agency

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- Prospects for nuclear cogeneration
- Economic assessment methodologies
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- Conclusion

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Drivers for cogeneration

- Improve economics
- Meet demand for energy-intensive non-electric products (desalination, hydrogen,…etc).
- Secure energy supply for industrial complexes
- Accommodate seasonal variations of electricity demand
- Match small and medium electrical grid with available large-size reactors

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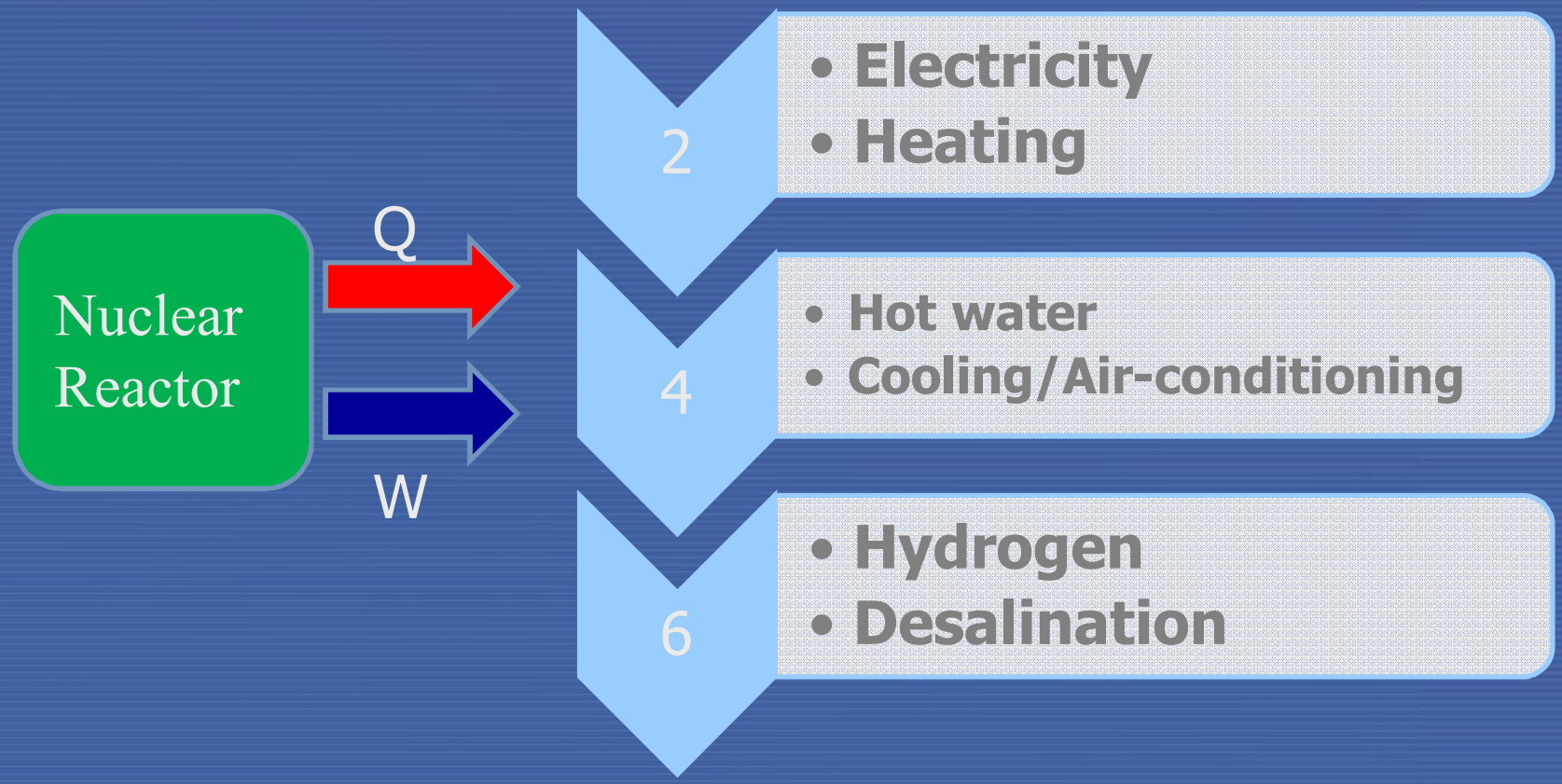
Cogeneration & Multi-generation



Efficiency Matters!:

$$\eta = \frac{O1 + O2 + O3 + \ldots\ldots + ON}{E1}$$

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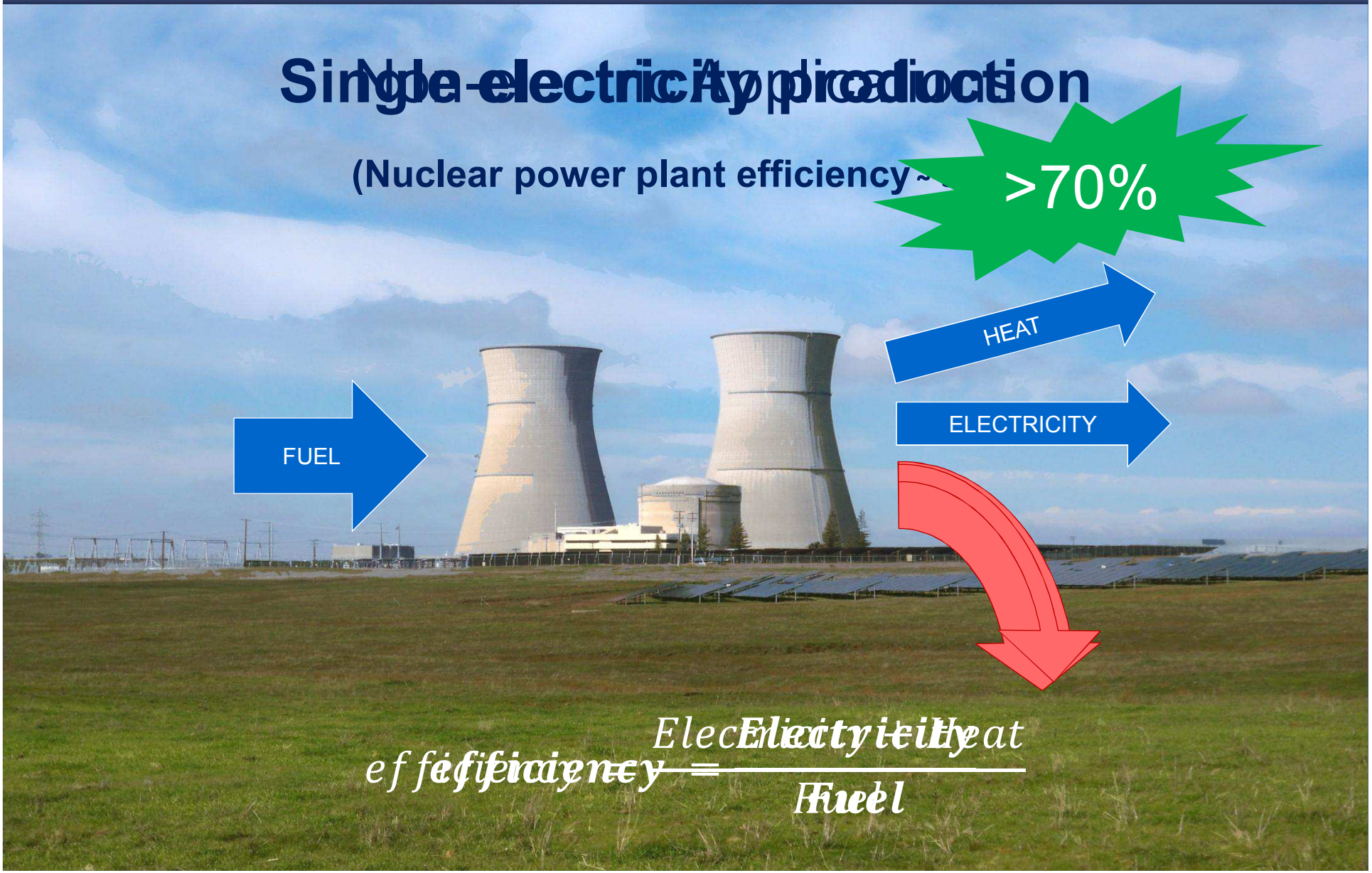
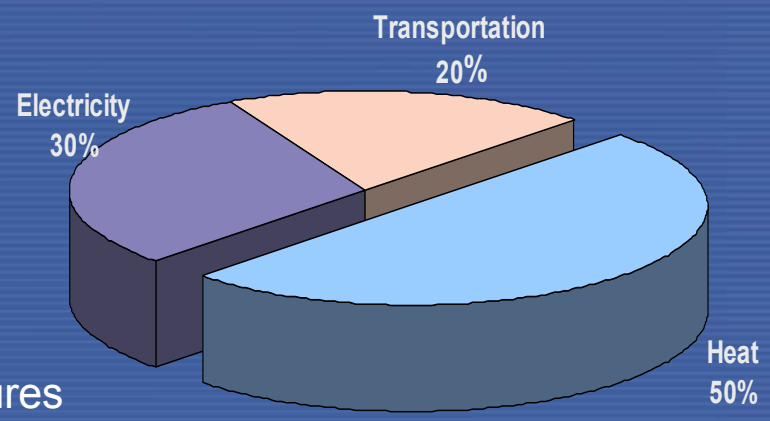
Why cogeneration with nuclear power?



$$\text{efficiency} = \frac{\text{Electricity} + \text{Heat}}{\text{Fuel}}$$

Why non-electric applications with nuclear?

- **Proven technology:** with **79** operative reactors and **750** reactor-years experience
- **Energy efficient**



- **Safe operation:** Inherent safety measures
- **Cost effective:** **Competitive price** of heat compared to fossil
- **Environmentally friendly:** **Zero CO_2** and **Less thermal pollution**

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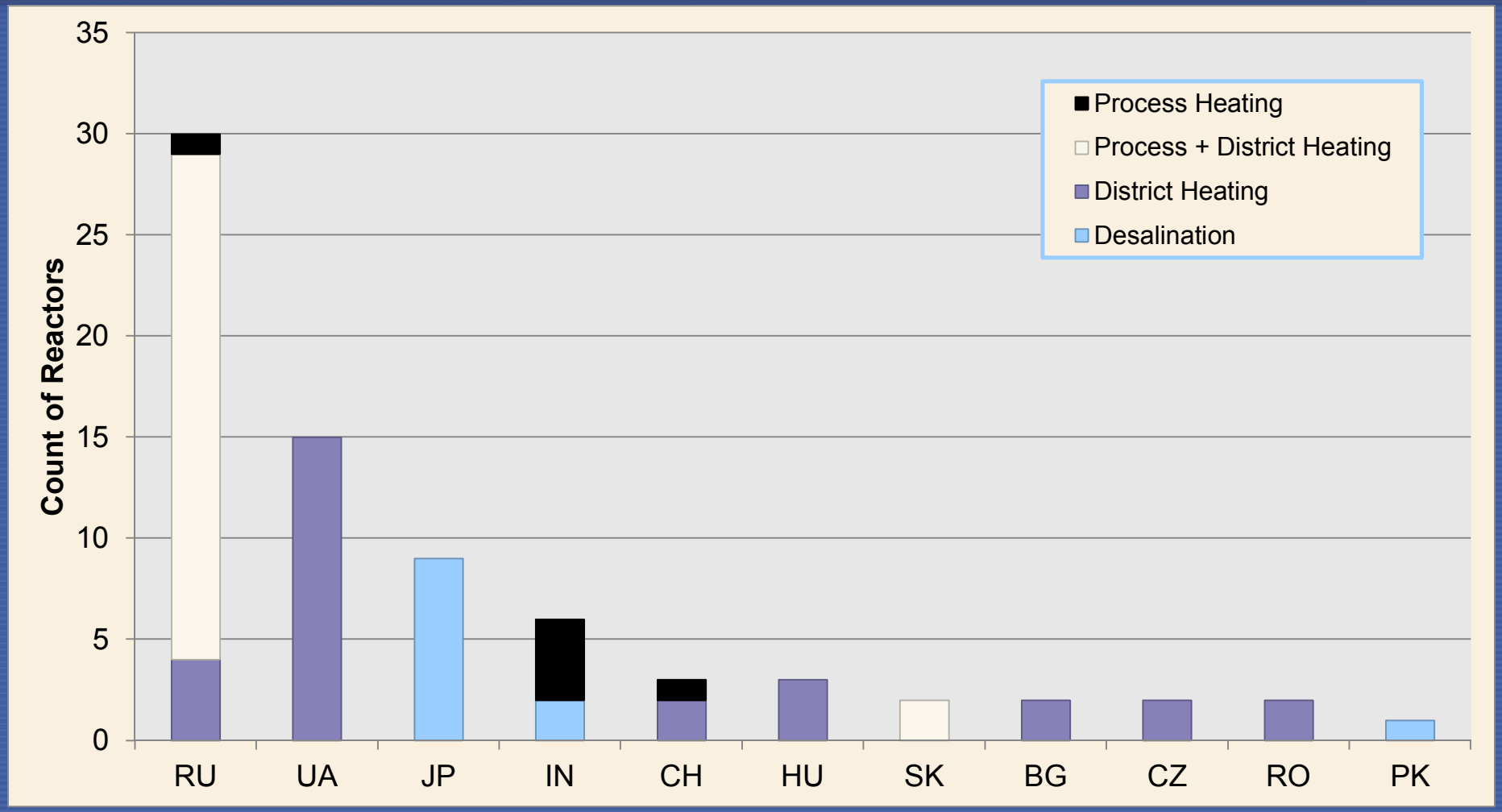
Experience on Cogeneration with Non-Electric Applications



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Merits of Cogeneration

- Improvement of efficiency
- Harnessing waste heat
- Improvement of economics due to sharing of infrastructures
- Mutual benefits of coupling (eg. provide necessary industrial quality water to the NPP or make use of the off-peak power)
- Reduce environmental impact (compared to two standalone plants)

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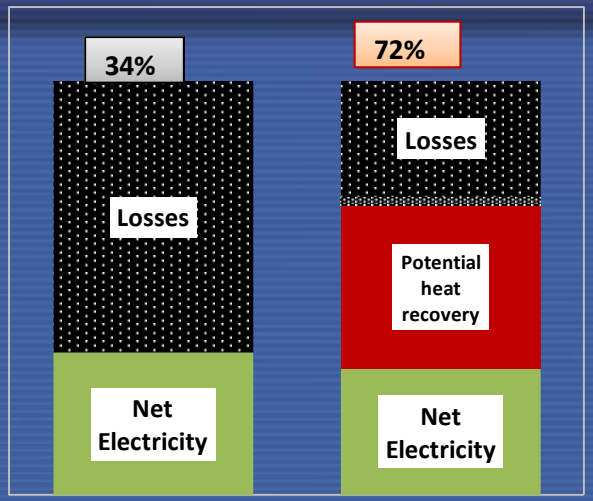
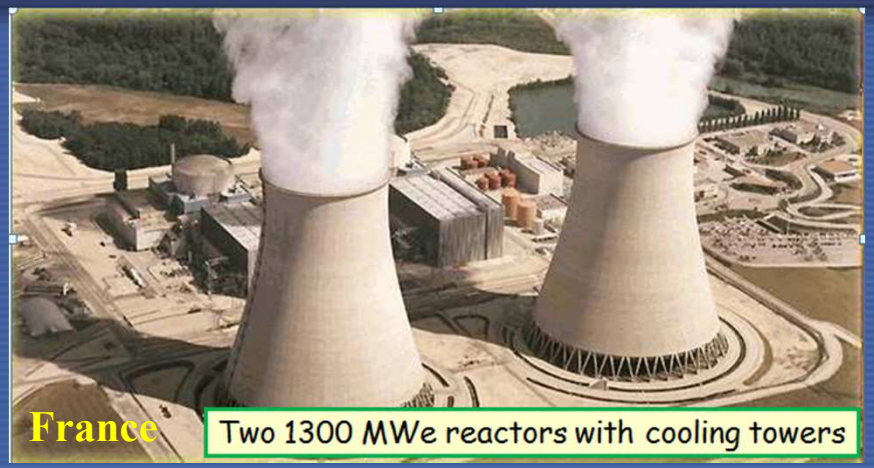
Improvement of efficiency: District Heating



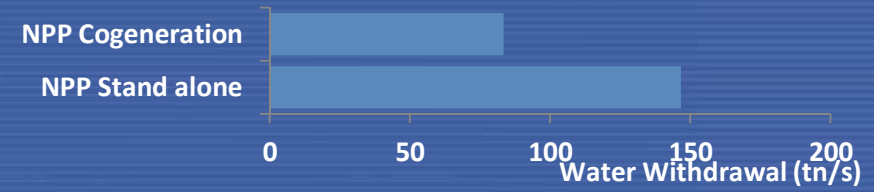


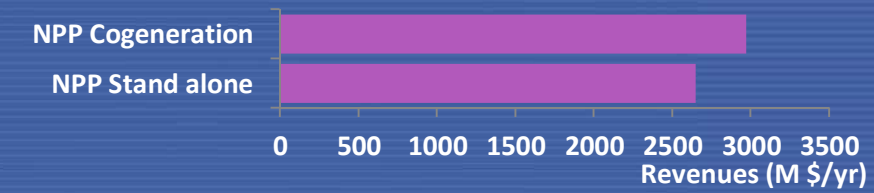
Loviisa 3 CHP

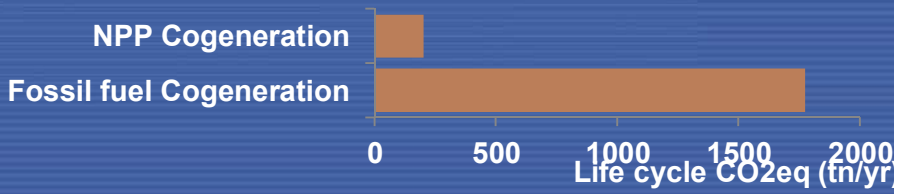
Basis of the Loviisa 3 CHP option

- Replacement of heat generated with fossil fuels
  - thermal energy consumption (**district heat**) 11 - 12 TWh per year
- Large reduction of carbon dioxide emissions
  - up to 4 million tons annually (6 % of the entire CO_2 emissions in Finland)
- Higher plant efficiency
  - reduction of heat discharge to the Gulf of Finland
  - net electrical power loss approx. 1/6 of the thermal power generated
- Steam extraction from the turbine
  - Before low-pressure turbines or several extractions from lp turbine
  - optimisation, and redesign vs. design of new turbine

22 October 2010 Harri Tuomisto 24 Fortum







Revenues from heat prodution	537M
Operational costs	186M
Total gain	**350M EURO**

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Loviisa 3 CHP

Next slides introduce some findings from the studies carried out by Fortum

Option of combined heat and power production (CHP) from the Loviisa Unit 3

Heat would be transported to the Helsinki metropolitan area:
- distance from Loviisa NPP is about 80 km
- heat capacity up to 1000 MW

Loviisa 3 CHP – technical data

District heat transport system

- Distance over 75 km (Loviisa – eastern Helsinki)
  - 2 x Ø 1200 mm pipes, PN25 bar, Q = 4 - 5 m^3/s
  - 4 - 7 pumping stations
    - total pumping power needed tens of MWs
    - compensates for heat losses
  - Control scheme
    - district heat water temperature or flow rate
  - Heat accumulator needed, heat distribution to the local district heat network via heat exchangers

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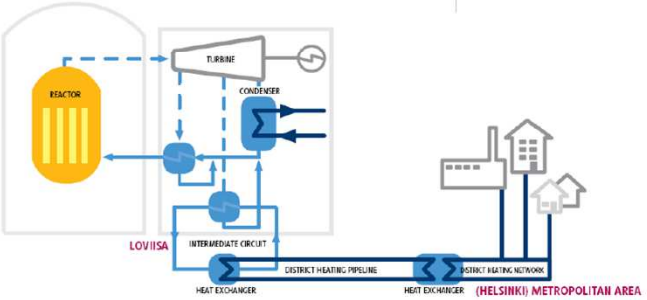
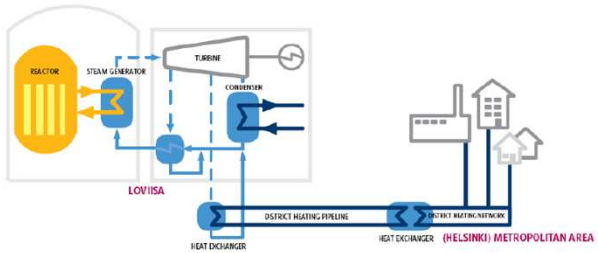
BWR connection

Heat extraction from a Boiling Water Reactor



nnection

ction from a Pressurized Water Reactor



Harnessing waste heat: PBMR for desalination

Waste heat: Heat extracted from NPP with no penalty to the power production

Using reject heat from the pre-cooler and intercooler of PBMR = 220 MW_{th}

at 70 °C + MED desalination technology

Desalinated water 15 000 – 30 000 m3/day

Cover the needs of 55 000 – 600 000 people

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Waste heat can also be recovered from PWR and CANDU type reactors to preheat RO seawater desalination

Improvement of economics

10% of 1000 MWe PWR for desalination

To produce 130 000 m3/day of desalinated water using 1000 MWe PWR
Total revenue (Cogeneration 90% electricity +10% water):

	Standalone	MED	RO
Electricity	7166 M$	6771 M$	7062 M$
Water	0	888 M$	672 M$
Total	7166 M$	7660 M$	7700 M$
		+7%	**+7.5%**

Using MED:

- Easier maintenance & pre-treatment
- Industrial quality water

Using RO :

- Increased availability
- No lost power as in MED
- Using waste heat to preheat feedwater by 15°C increases water production by ~13%

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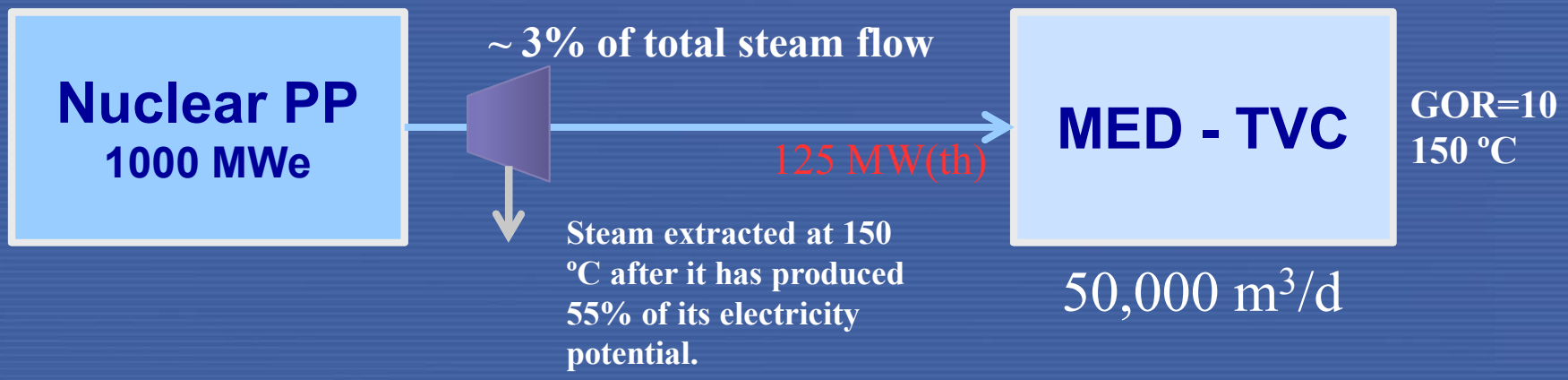
Improvement of economics with small desalination plants



3% x 45%= 1.35% more steam needed in order to compensate the power lost

- Cheap nuclear desalination
  Fuel cost ~ 15% of total electricity costs

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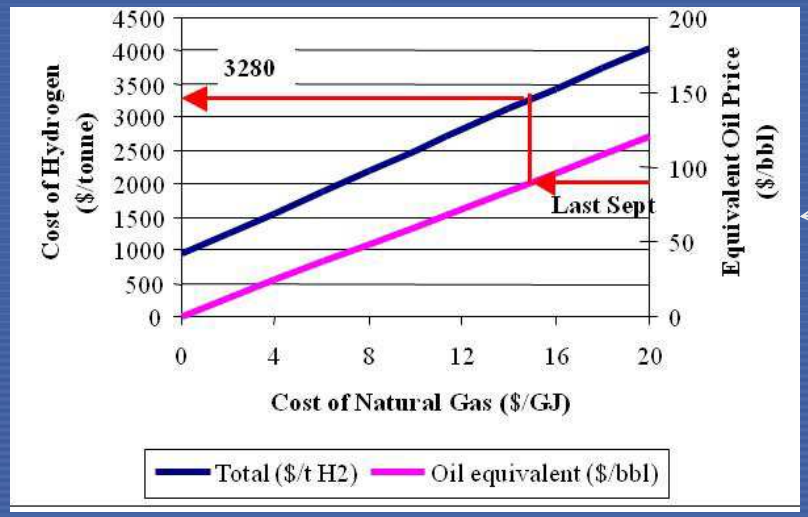
Source : Rognoni et al., IJND 2011

Better economics during off-peak power

Hydrogen production

	$/kg
Conventional Electrolysis (> 1000 kg/day)	4.15
Dedicated nuclear HT Steam Electrolysis plant	$3.23
Off-peak grid electricity ($0.05/kW hr), HTSE	$2.50
Large-scale Steam Methane Reforming	$1.5 – 3.5



directly dependent on the cost of natural gas, no carbon tax

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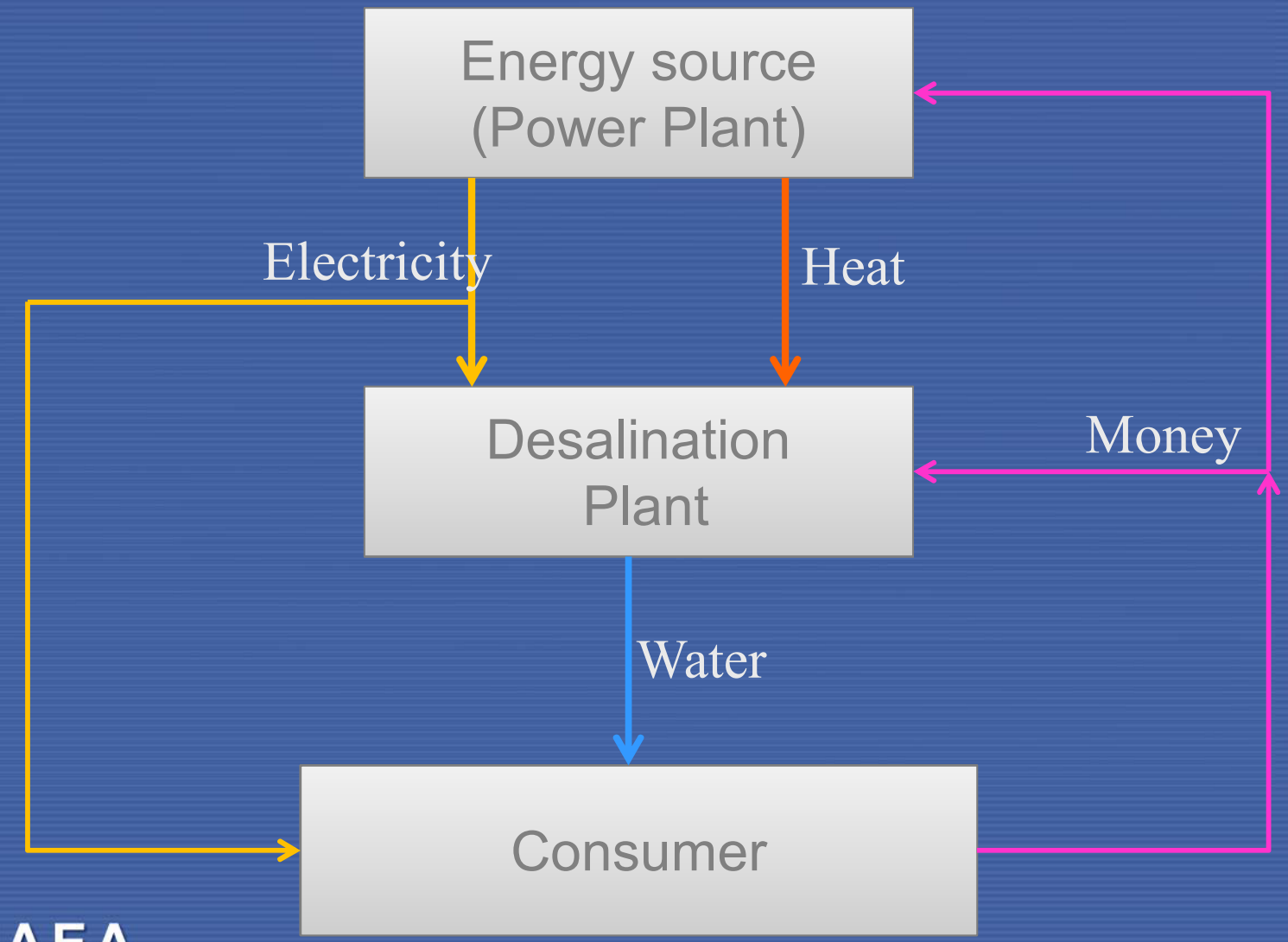
Economic assessment methodologies



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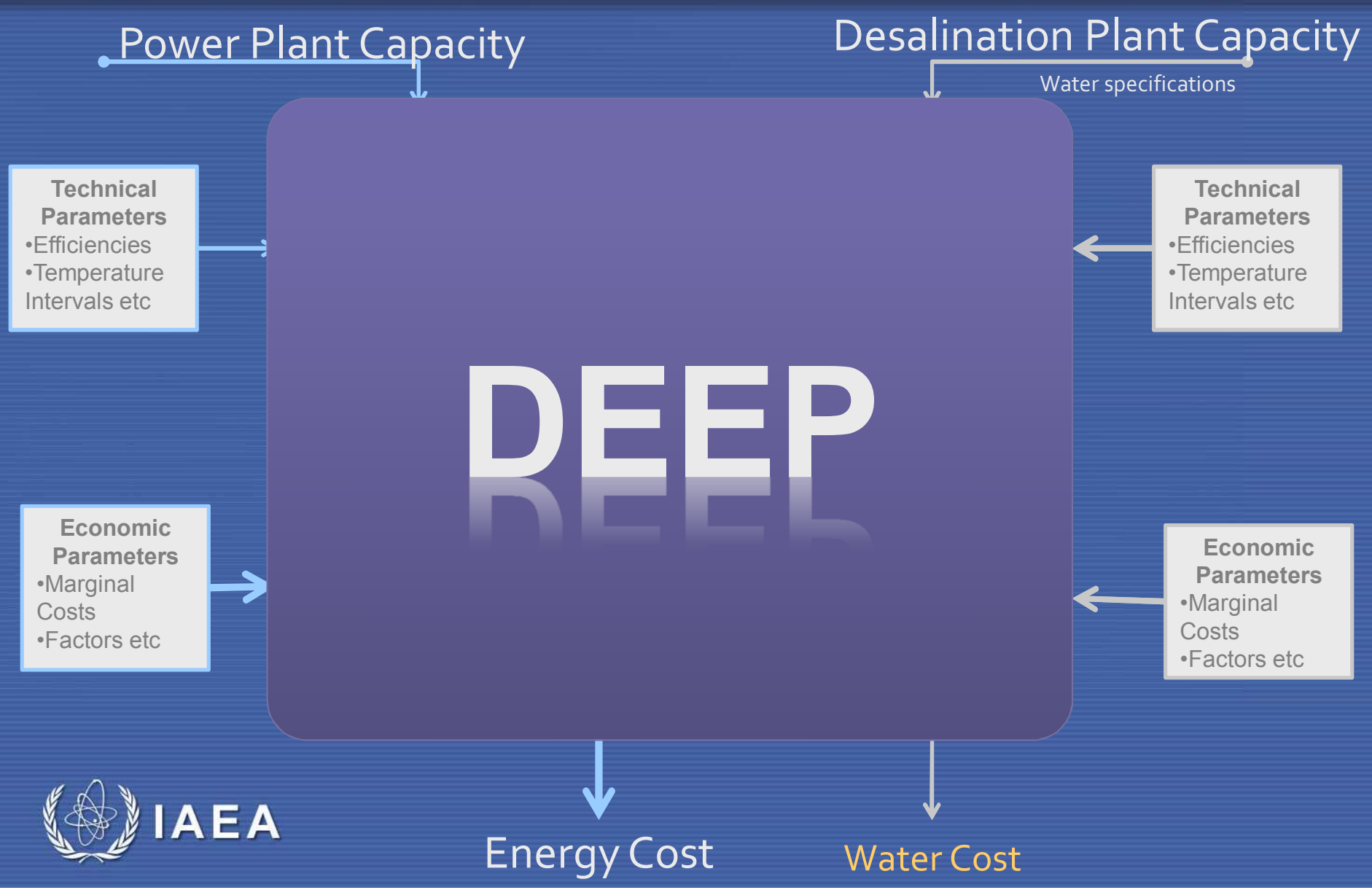
DEEP Model Overview



Water Cost from Nuclear Desalination

- Depends on the economics of
  - ✓Power Plant
  - ✓Desalination Plant
- Coupling configuration affects water cost
- Methods to allocate costs of dual purpose plants
  - ✓Proportional:
  - ✓Power – water credit : the water (or the power) plant gets all the benefits of cogeneration
  - ✓Exergetic : The cost is attributed according to the value of exergy flows

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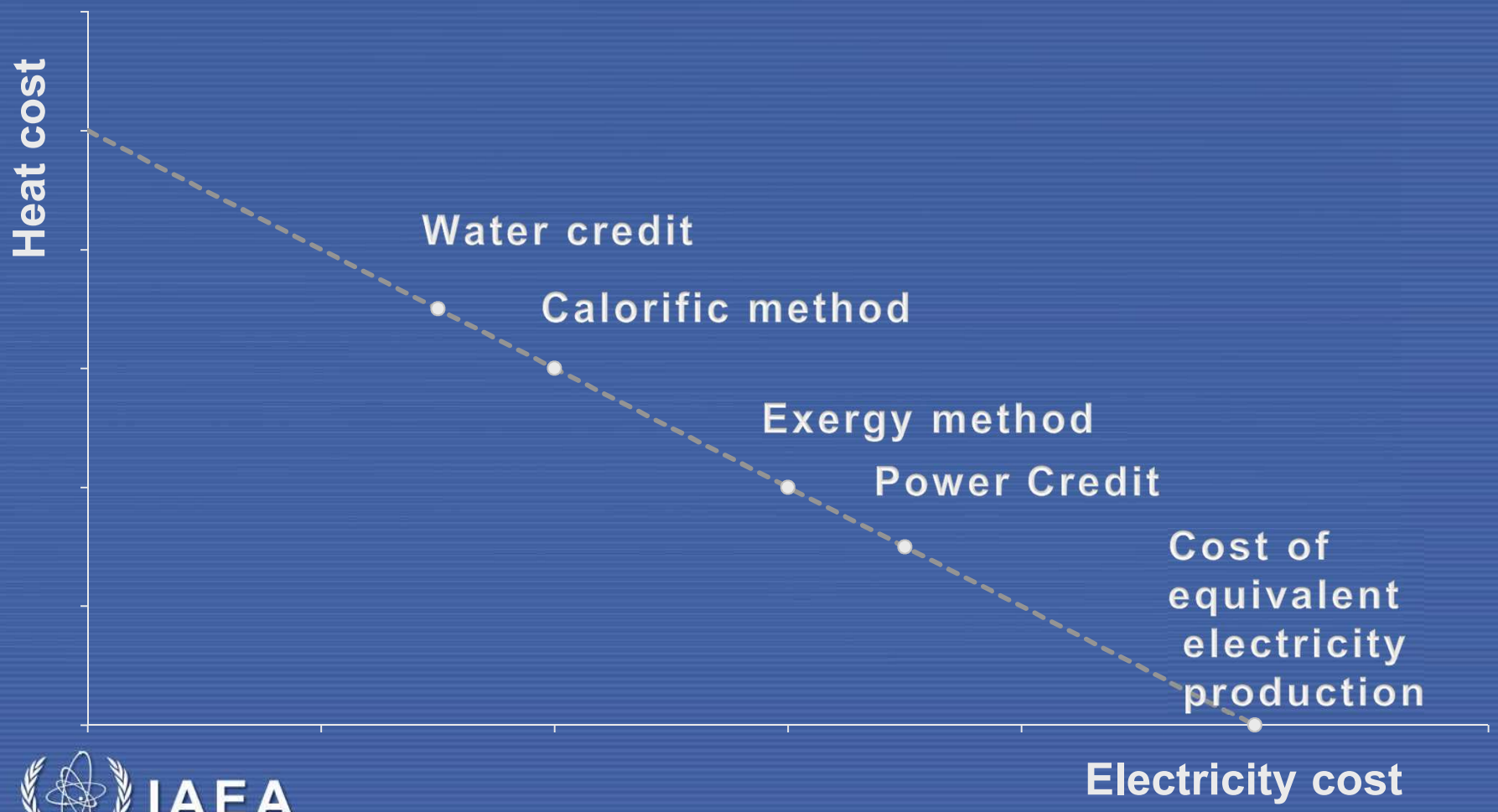
Cost allocation methods in dual purpose plants



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Proportional method

Divides the total plant cost between the two products: electricity and heat in a certain ratio, selected on the basis of various criteria.

e.g. comparison of the dual purpose plant with alternative single purpose plant to establish a ratio of heat to electricity costs

- Disadvantages:
  - Difficulty of accurately defining the costs of equivalent single purpose plants
  - Market distortions (direct or hidden subventions.)

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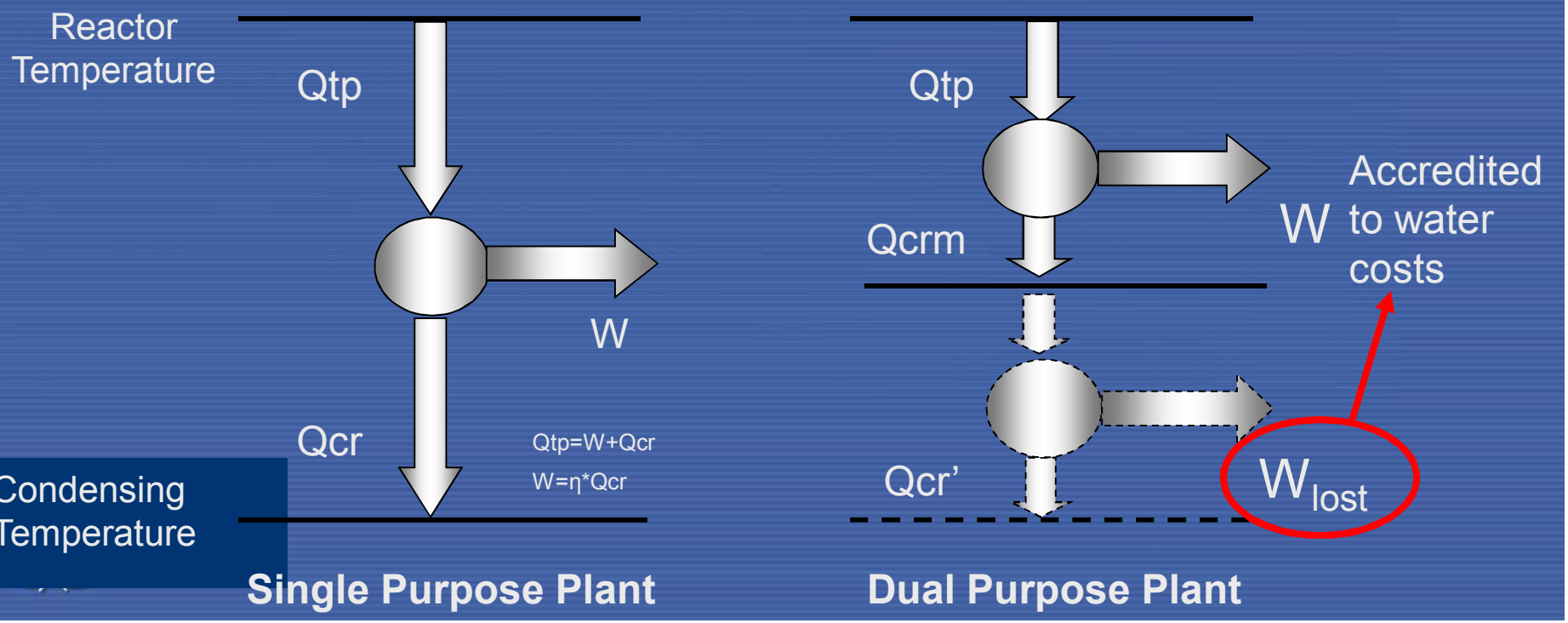
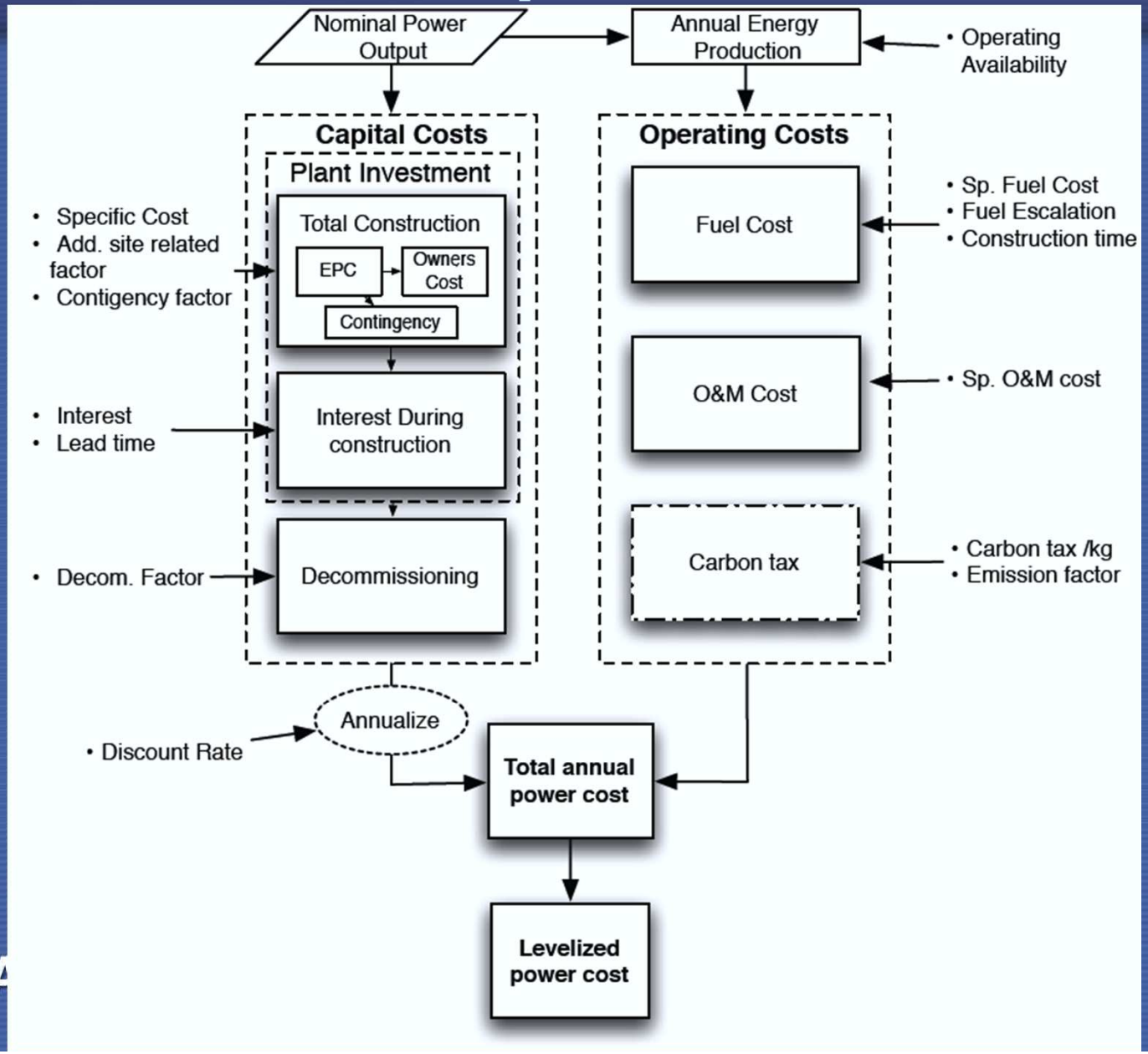
Power Credit method

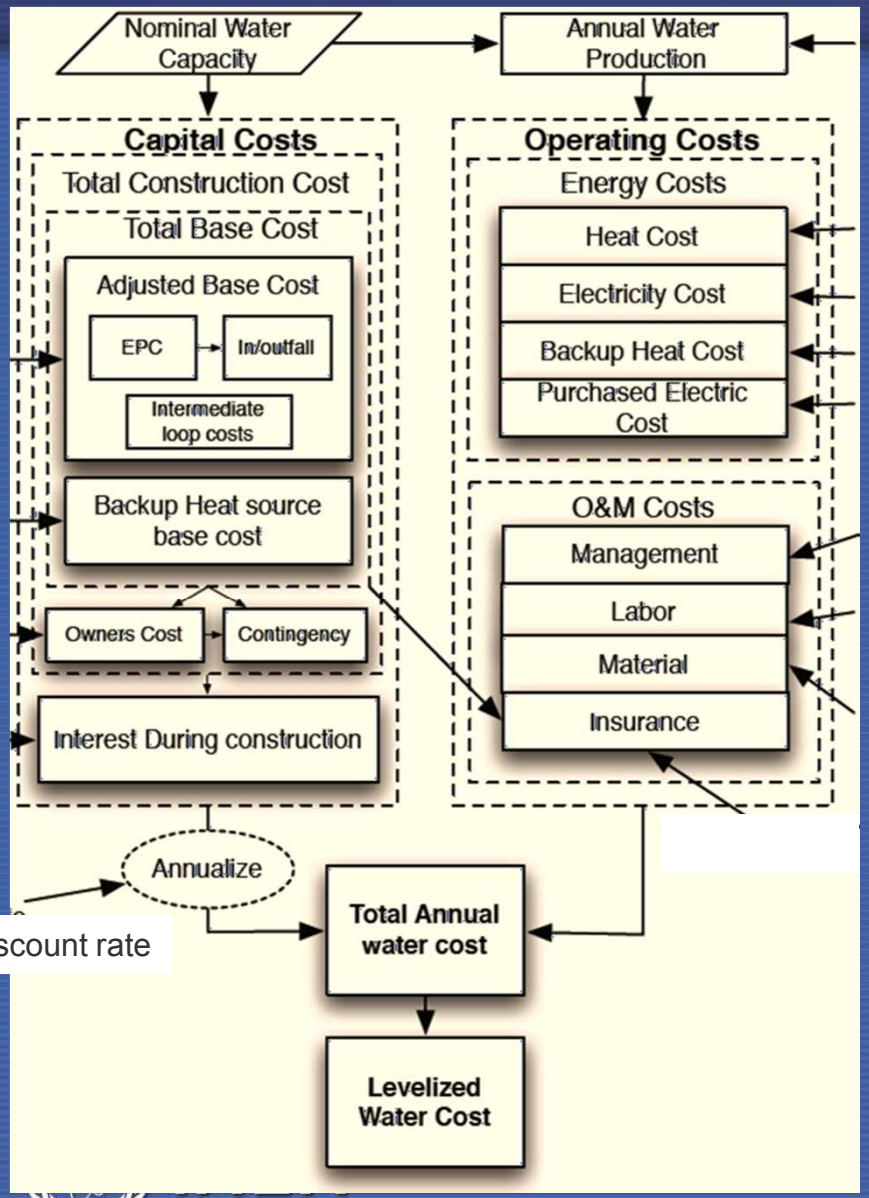
- ‘Power credit’ method is the heart of DEEP.
- Water is credited with all of the economic benefits associated with the plant being dual purpose
  - **Electricity Cost** : Cost of Electricity from an Imaginary single power plant
  - **Heat Cost** : Cost of electricity that could be produced if heat was not extracted at a higher temperature



Power Cost Components

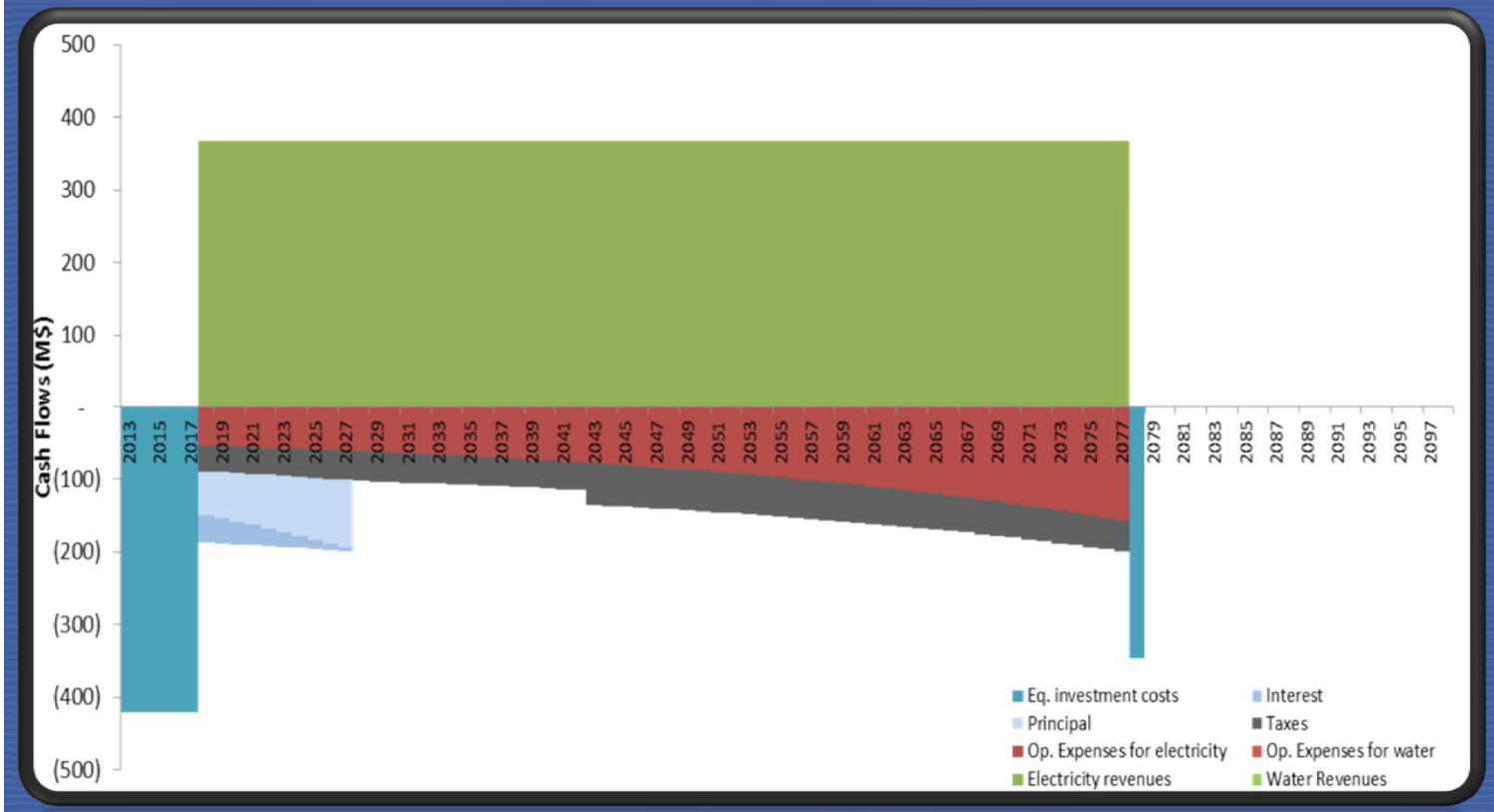


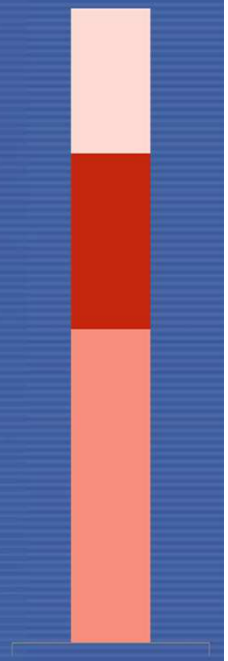
Water Cost Components



The levelized cost ($/m^3) of water is the discounted cost of all expenditures associated with the design, construction, operation, maintenance, energy divided by the discounted values of the quantities of energy produced

Cash flow analysis of a ND project





Levelised cost

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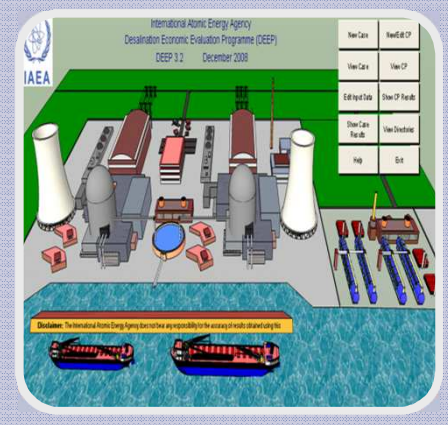
IAEA tools for support on Non-Electric Applications



DEEP

- **Quick identification of the lowest cost options for providing desalted water and/or power at a given location**

DE-TOP

- **Quick identification of possible coupling configurations and analysis of the effects of heat extraction on the power production**

HEEP

- **Identification of cost options for hydrogen production, distribution and storage using nuclear or conventional power.**

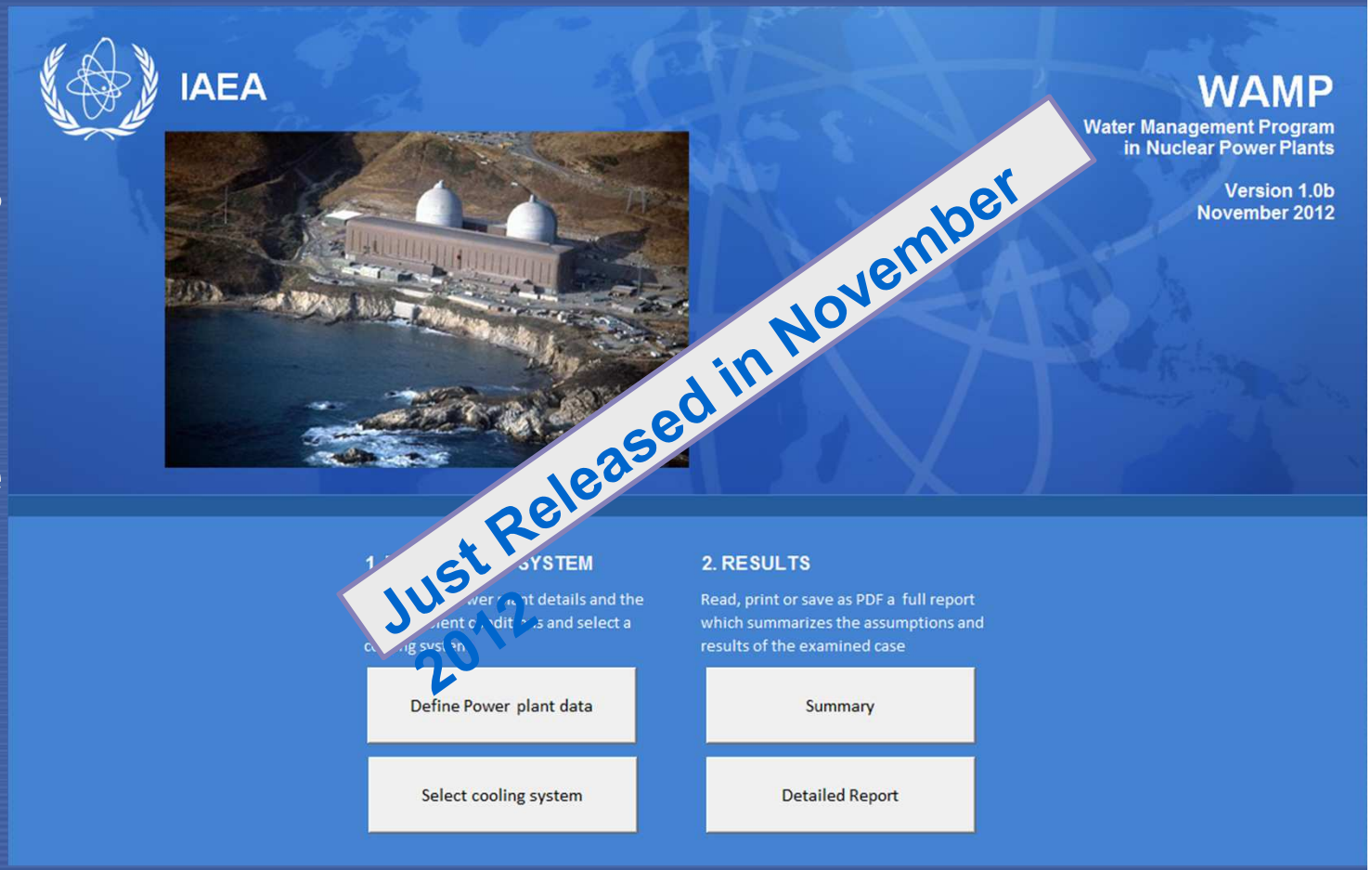
Toolkit

- **Contains hyperlinks to all relevant documents on nuclear desalination.**

IAEA Toolkit on Water Management in NPPs (WAMP)

Assist to:

- Estimate water needs in NPPs
- Make comparative assessment of various cooling systems)



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Conclusions

- Nuclear cogeneration is feasible and economically viable
- Challenges for nuclear cogeneration:
  - Disparity between nuclear & heat markets
  - Demonstration of NPPs tailored for industry
  - Licenseability of tailored NPPs
  - Overcoming specific issues and concern of tailored NPPs (siting, time required for planning, construction, financial risk, ..etc)
  - Economics

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...Thank you for your attention