Non-Electric Applications of Advanced Reactors and SMRs

Rami El-Emam

Outlines!

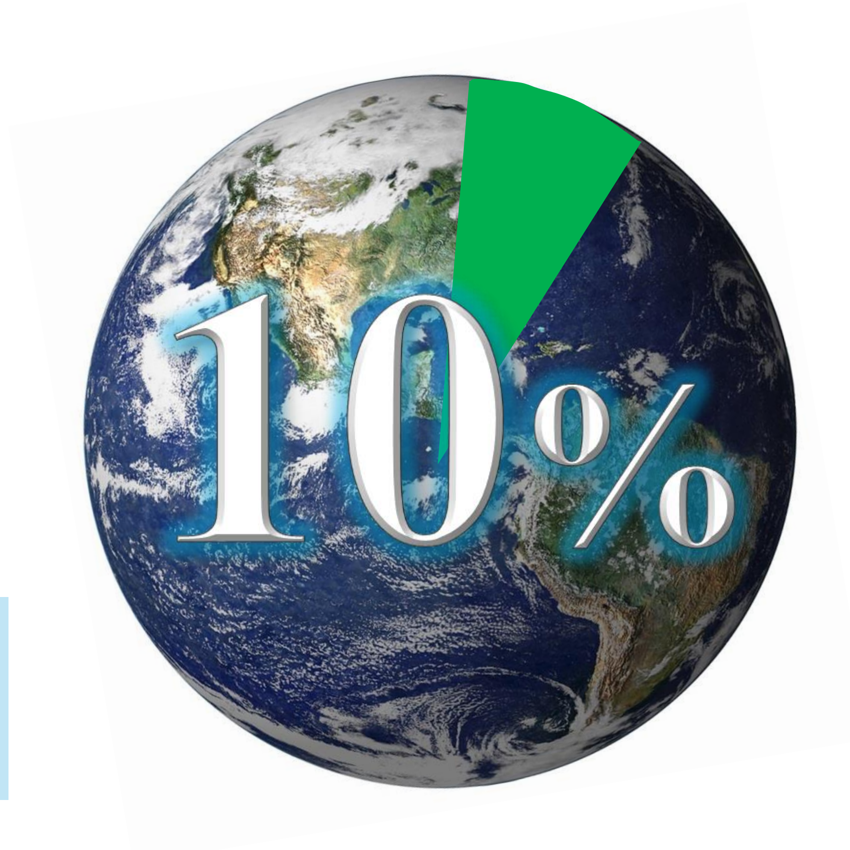
- **Introduction**
- **Nuclear Cogen: Technologies & Status**
- **Assessment Tools on Non-Electric Applications**

NUCLEAR POWER TODAY

Nuclear Power Today

Total Number of Operating Reactors today is **440** reactor with total net electrical capacity of **390,000 MWe.**

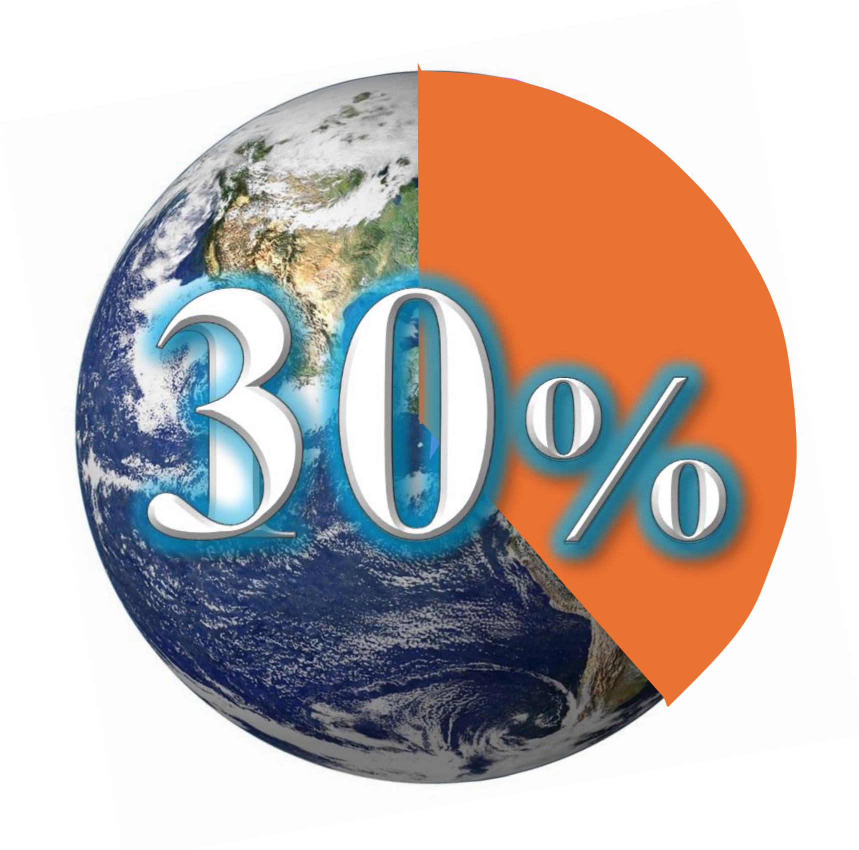
This is 10% of Global Electricity Production



Nuclear Power Today

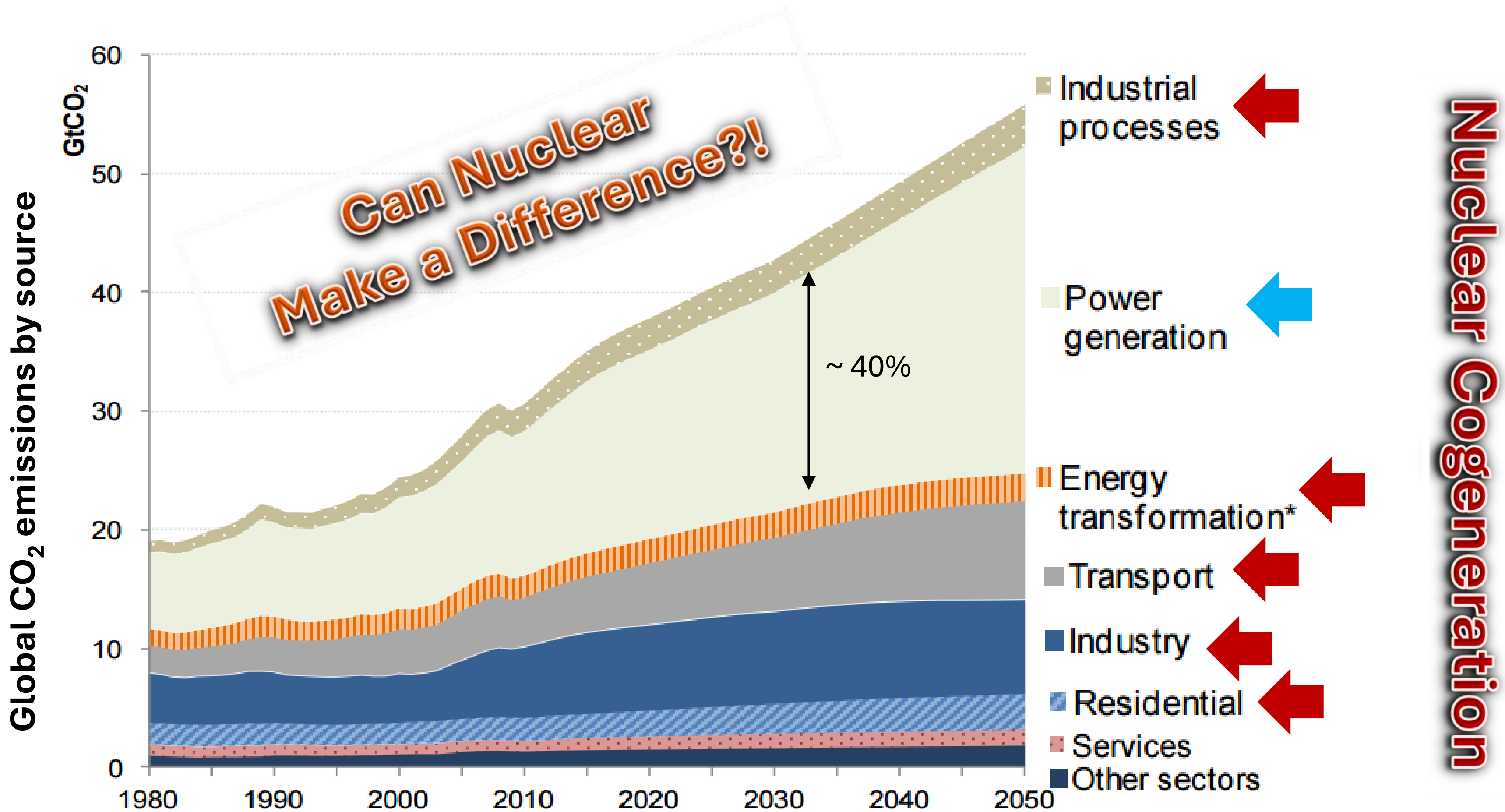
Total Number of Operating Reactors today is **440** reactor with total net electrical capacity of **390,000 MWe.**

Second Low-Carbon Power Source (~30%)



NUCLEAR ENERGY & CLIMATE CHANGE

Role in Climate Change Mitigation



Source: OECD, Environmental Outlook Baseline, 2011

SUSTAINABLE DEVELOPMENT GOALS

Nuclear Cogeneration & SDGs

P O W E R of TODAY's NUCLEAR P O W E R

more than 7 0 0 , 0 0 0 M W (th)

heat wasted from today's operating reactors

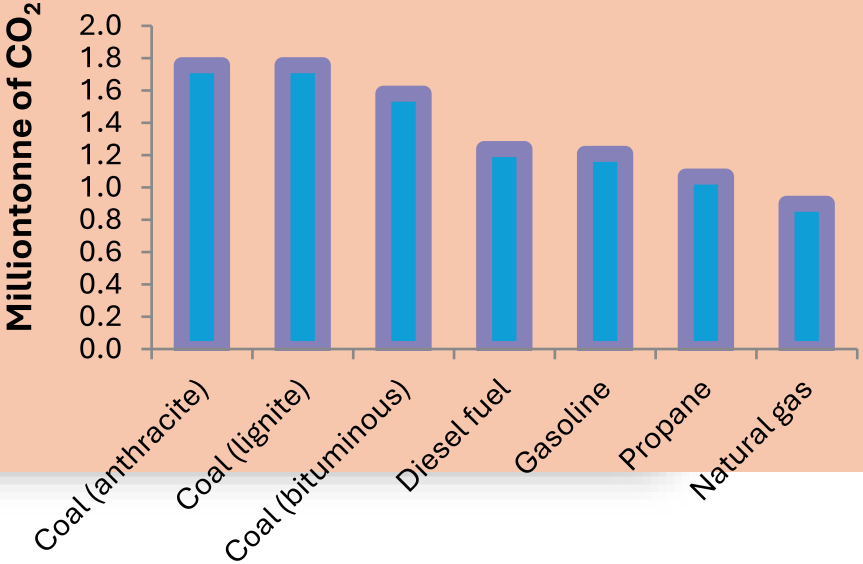
Role in Climate Change Mitigation

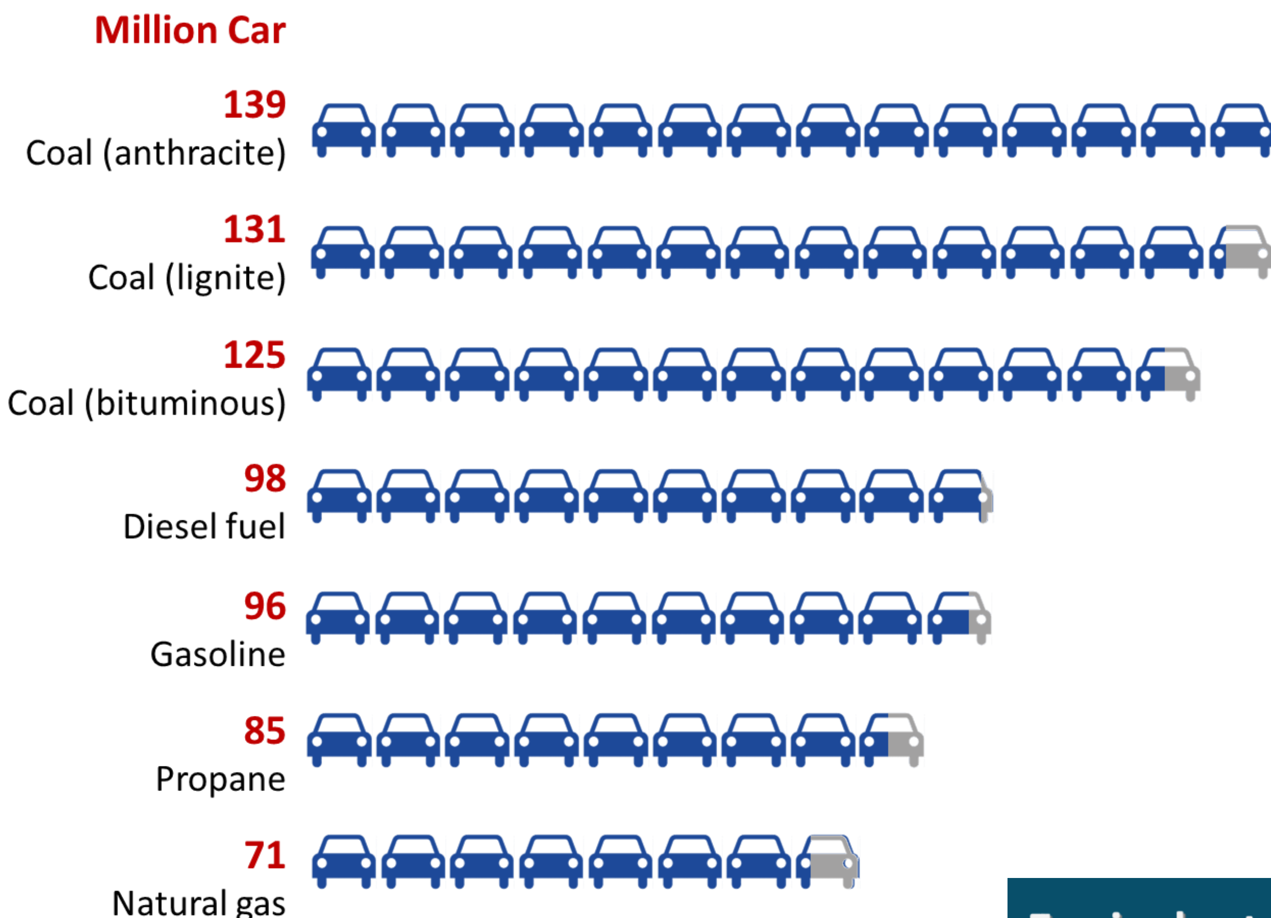
Waste heat from these reactors is
700,000 ~ 1,000,000 MW(th)!!

Assume: ~ 25% recovery of waste heat

This is equivalent to daily reduction of 1 - 2 Million tonnes of CO_2 emissions

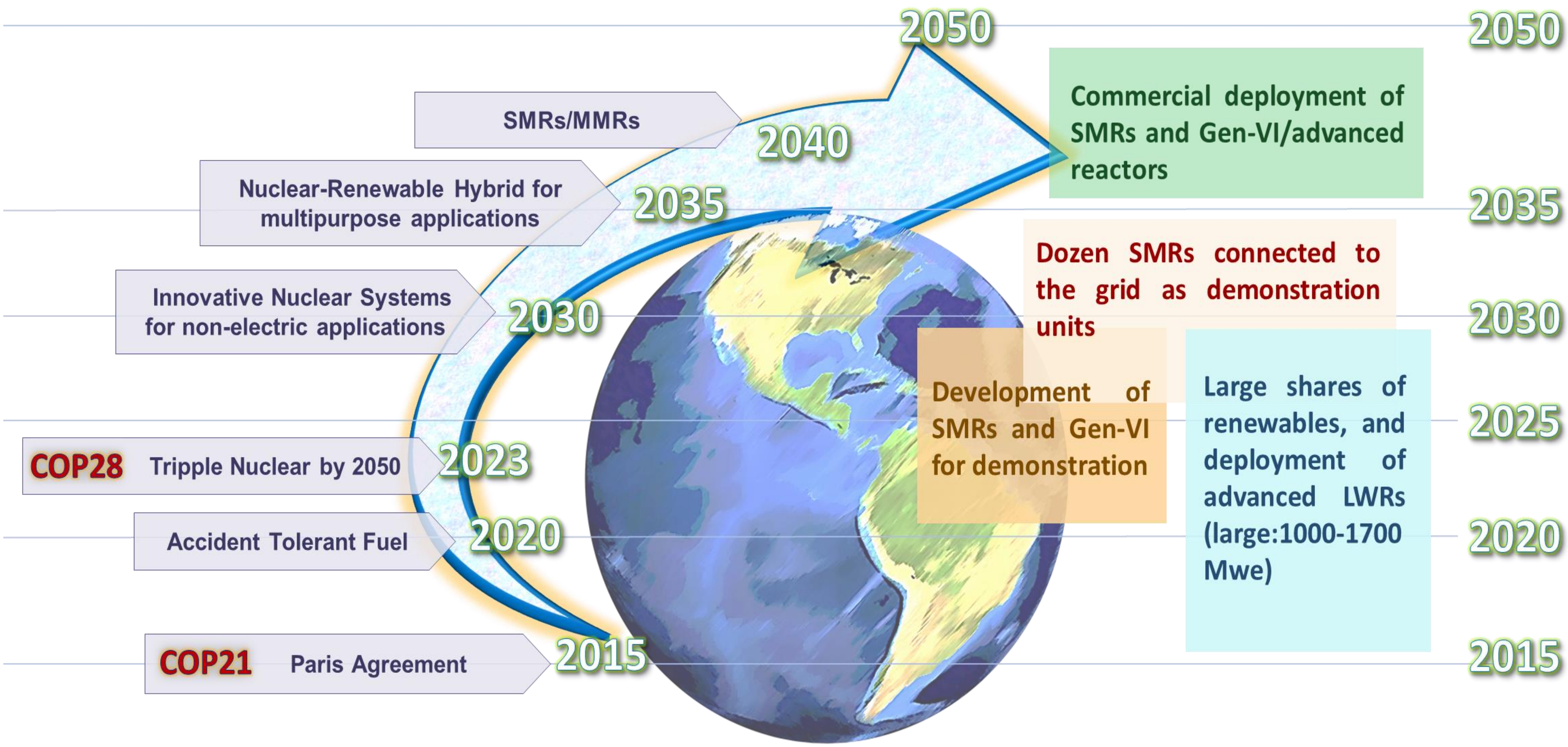
Based on the type of fossil fuel would be used to cover this thermal demand





Equivalent cars taken off roads in a year when nuclear waste heat is recovered to replace carbon-based heat applications

ROADMAP OF NUCLEAR ENERGY INNOVATIONS



STATUS OF NUCLEAR COGENERATION

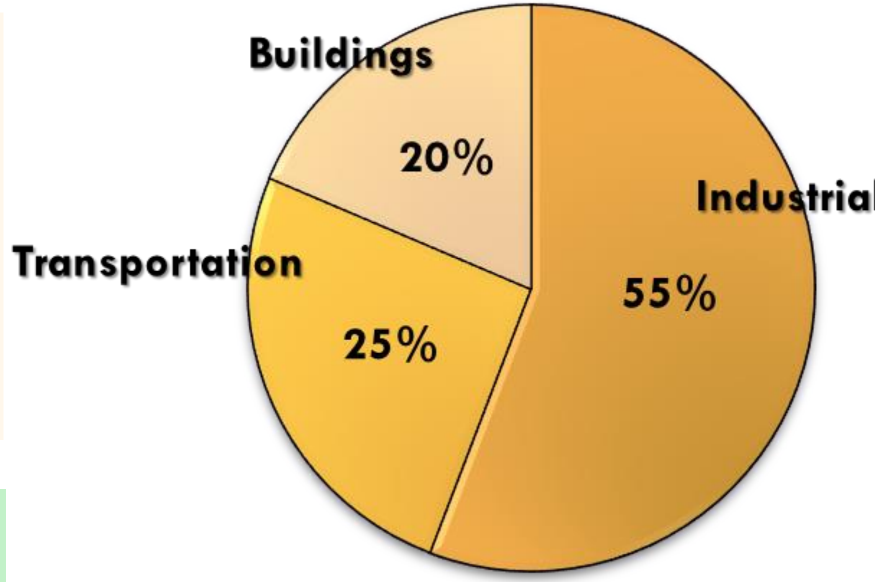
- Nuclear cogeneration is a well proven technology with over 750 reactor years of operation in different applications.

- About 15% of the currently operating nuclear power plants are used to supply heat

POTENTIAL OF NUCLEAR COGENERATION

Nuclear potential is in penetrating **Transportation** and **Heat** (industrial and buildings) sectors using Nuclear Cogeneration of Power and Heat

The share of electricity used in **transportation** doubles between 2015 and 2040 as more plug-in electric vehicles enter the fleet and electricity use for rail expands

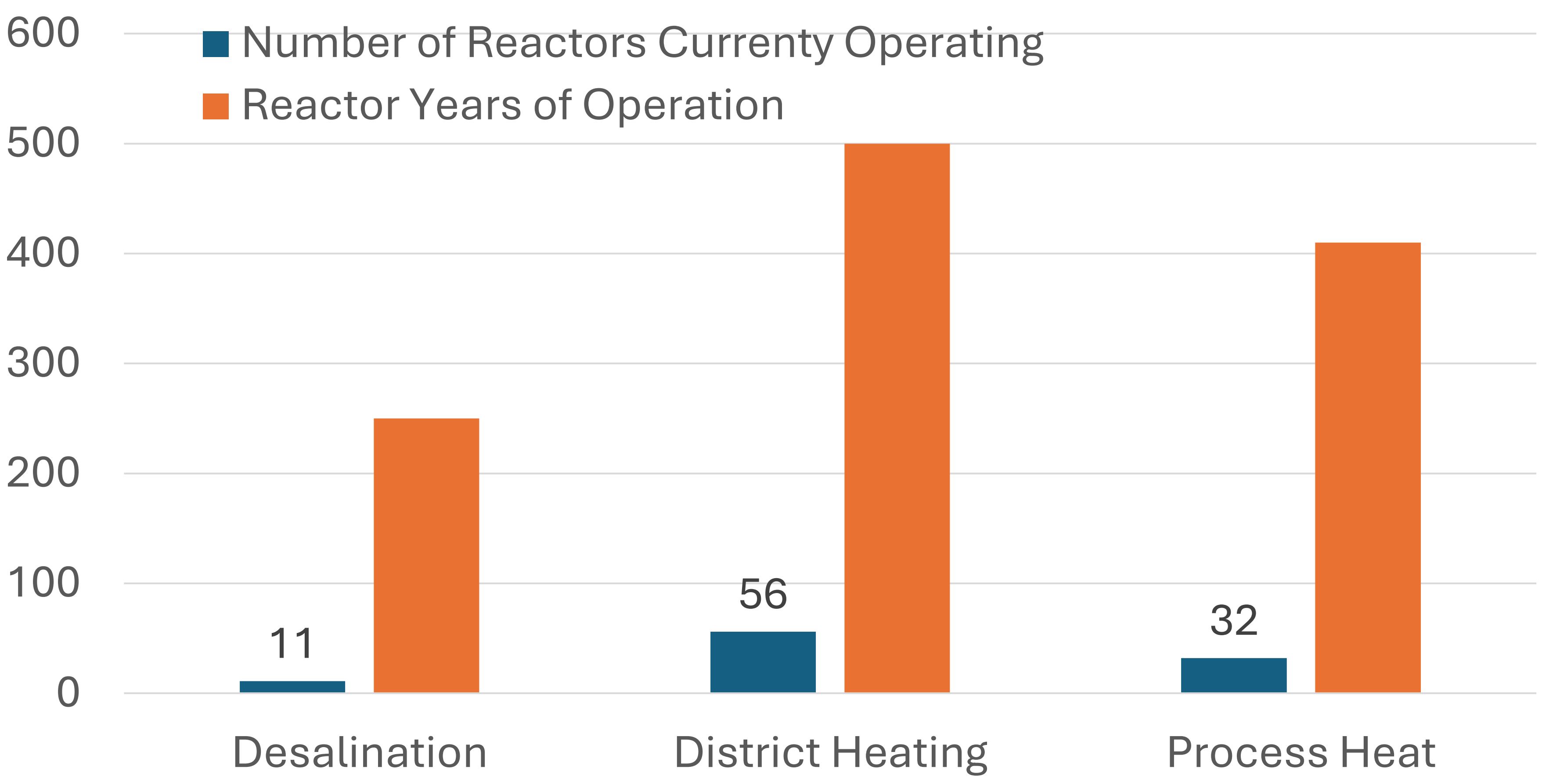


World energy consumption by end-use sector

The industrial sector includes mining, manufacturing, agriculture, and construction
The buildings sector includes commercial and residential structures (electricity, heating,..)

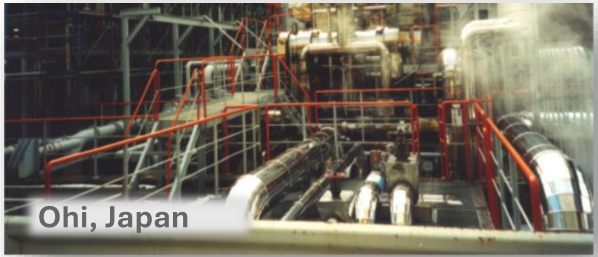
Data extracted from IEA, 2017

Status of Nuclear Cogeneration

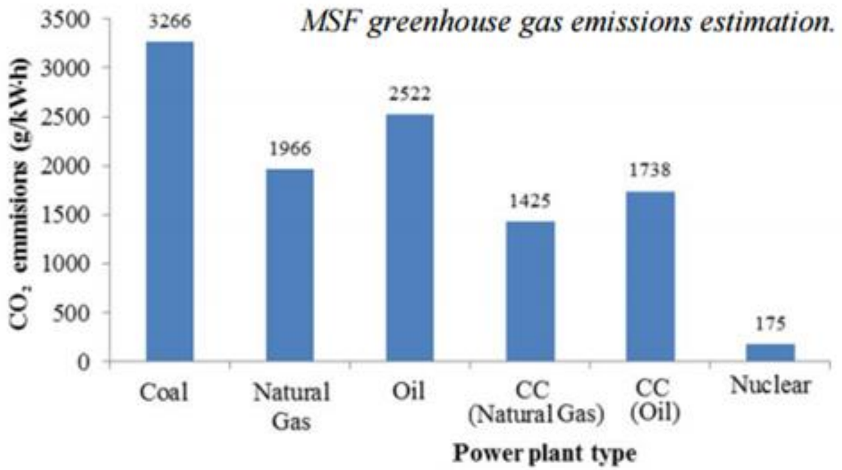


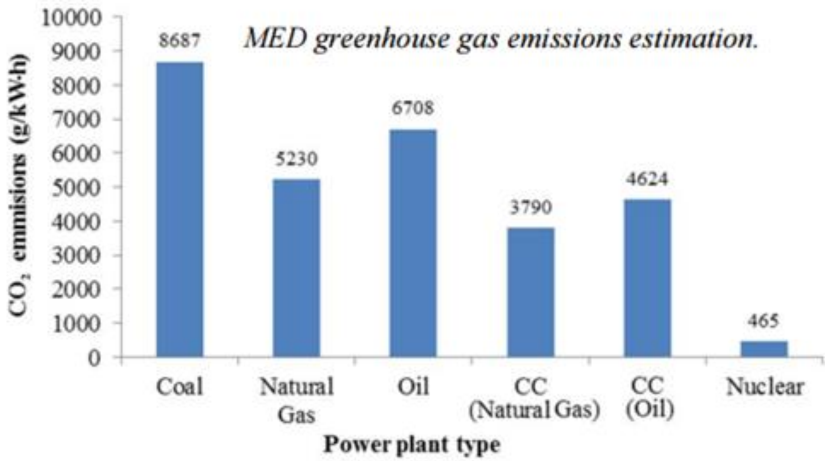
Experience on Nuclear Desalination

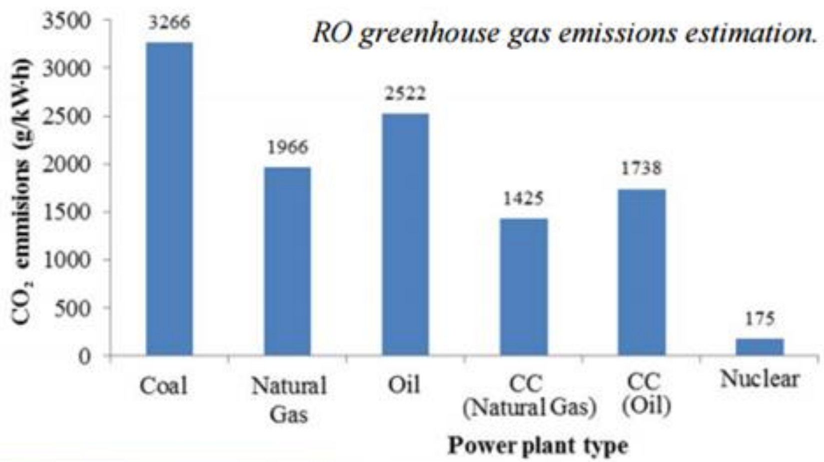
Plant name	Location	Gross power MW(e)	Water capacity [m³/d]	Reactor type/ Desal. process
Shevchenko	Kazakhstan	150	80000 – 145000	FBR/MSF&MED
Ikata-1,2	Japan	566	2000	LWR/MSF
Ikata-3	Japan	890	2000	LWR/RO
Ohi-1,2	Japan	2 x 1175	3900	LWR/MSF
Ohi-3,4	Japan	1 x 1180	2600	LWR/RO
Genkai-4	Japan	1180	1000	LWR/RO
Genkai-3,4	Japan	2 x 1180	1000	LWR/MED
Takahama-3,4	Japan	2 x 870	1000	LWR/RO
Diablo Canyon	USA	2 x 1100	2180	LWR/RO
NDDP	India	2 x 170	1800	PHWR/RO
Karachi	Pakistan	175	1600	MED



GHG Emissions for *Nuclear Desalination*







Nuclear Hydrogen Production

Current nuclear reactors:

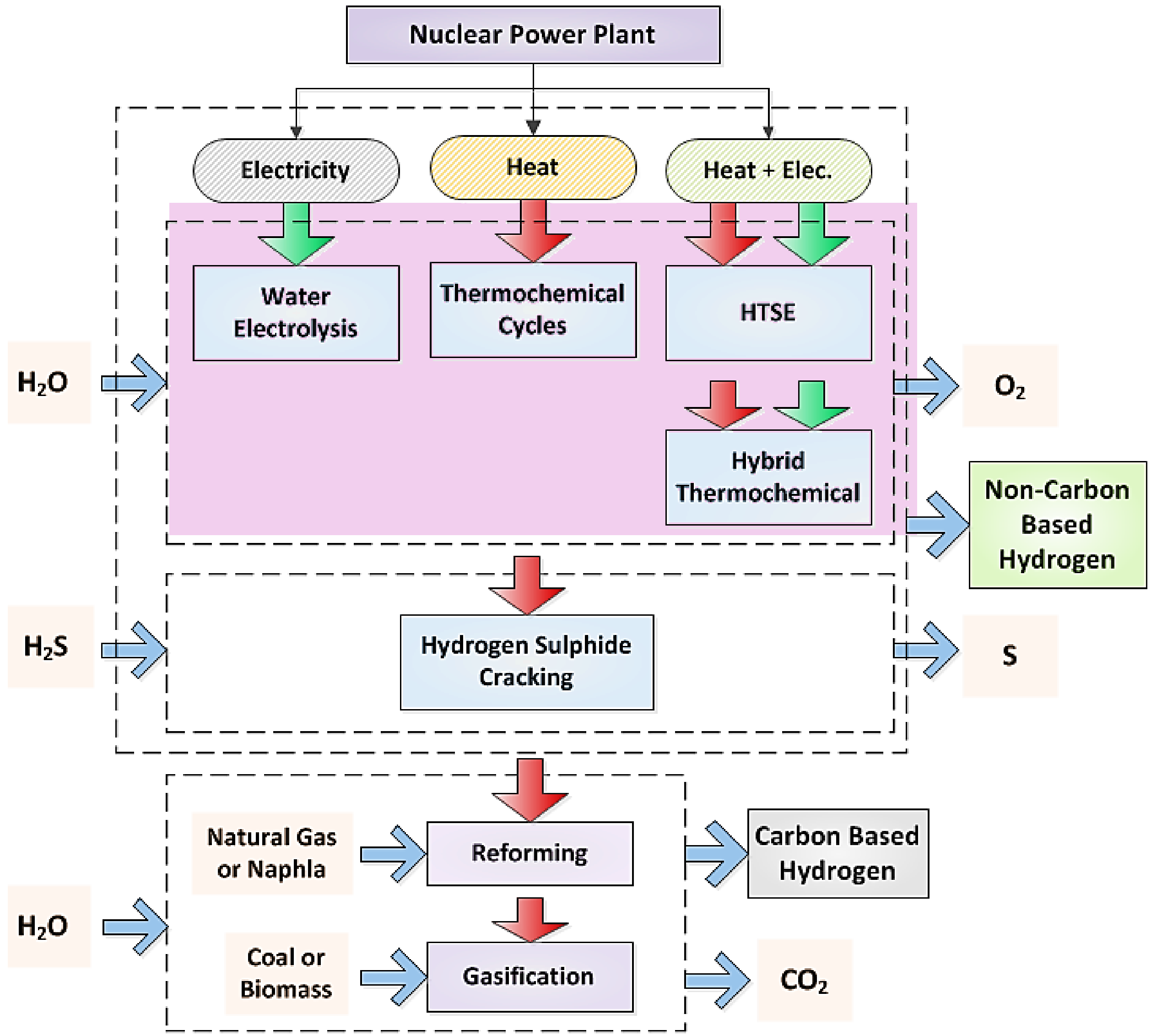
- Low-temperature electrolysis

- Off-peak power or intermittent
- HTSE

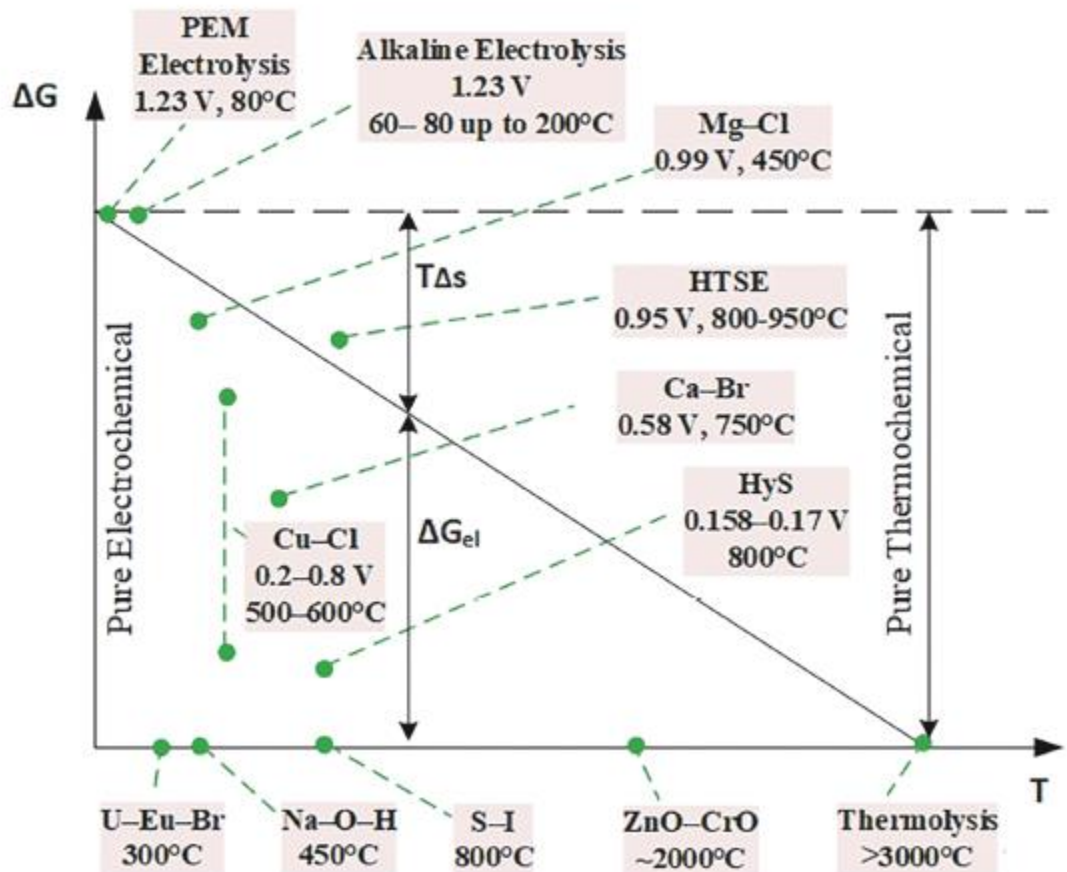
Future nuclear reactors:

- Thermochemical/hybrid thermochemical cycles, *efficiency (up to 95%)*

✓ Sulfur- Iodine cycle.
✓ Sulfur-Bromine hybrid Cycle cycle
✓ Copper Chlorine cycle
✓ .... etc



Maximum temperatures and theoretical electrical energy requirements of selected hydrogen production methods



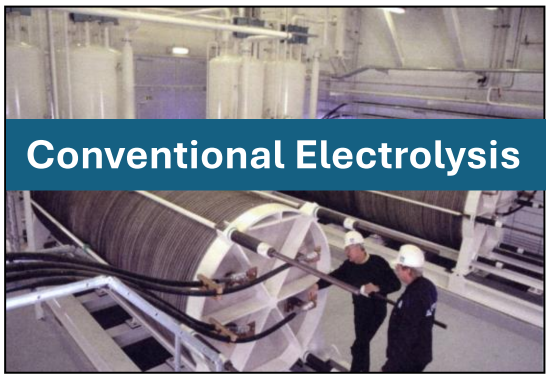
advanced nuclear reactor (Gen-IV) for Hydrogen Production

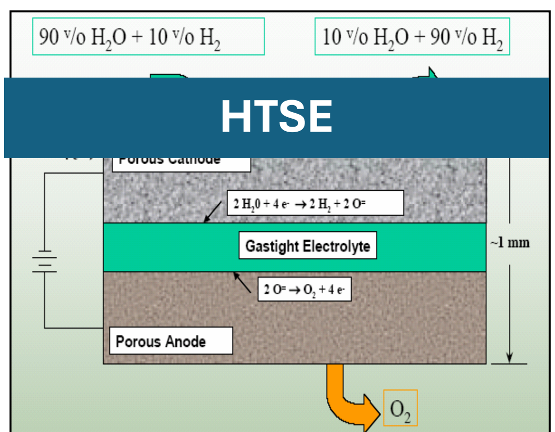
		GEN IV - Advanced Nuclear Technologies					
		SCWR	VHTR	SFR	GFR	MSR	LFR
Specifications	Core outlet temperature ˚C	500 ~ 625	750 ~ 950	450 ~ 550	750 ~ 850	650 ~ 850	450 ~ 800
	Efficiency (electric based) %	44 ~ 48	40 ~ 50	38 ~ 42	45 ~ 48	45 ~ 55	42 ~ 45
	Thermodynamic power cycle						
	Brayton Cycle	-	He	S-CO_2	He	He	S-CO_2
	Rankine Cycle	Steam	Steam	Steam	-	-	Steam
Hydrogen Production Technologies	**Electrolysis**						
	PEM electrolysis (<100˚C)	✓	✓	✓	✓	✓	✓
	Alkaline electrolysis (~200˚C)	✓	✓	✓	✓	✓	✓
	High temp electrolysis (> 800˚C)	✓	✓	✓	✓	✓	✓
	Thermochemical/Hybrid Cycles						
	Sulfur Iodine (> 800˚C)	-	✓	-	✓	-	-
	Hybrid Sulfur (> 800˚C)	-	✓	-	✓	-	-
	Copper Chlorine (> 600˚C)	✓	✓	-	✓	✓	-
	Carbon Based Thermochemical						
	Steam methane reforming (> 700˚C)	-	✓	-	✓	✓	-
	Coal/Biomass gasification (> 650˚C)	✓	✓	-	✓	✓	-

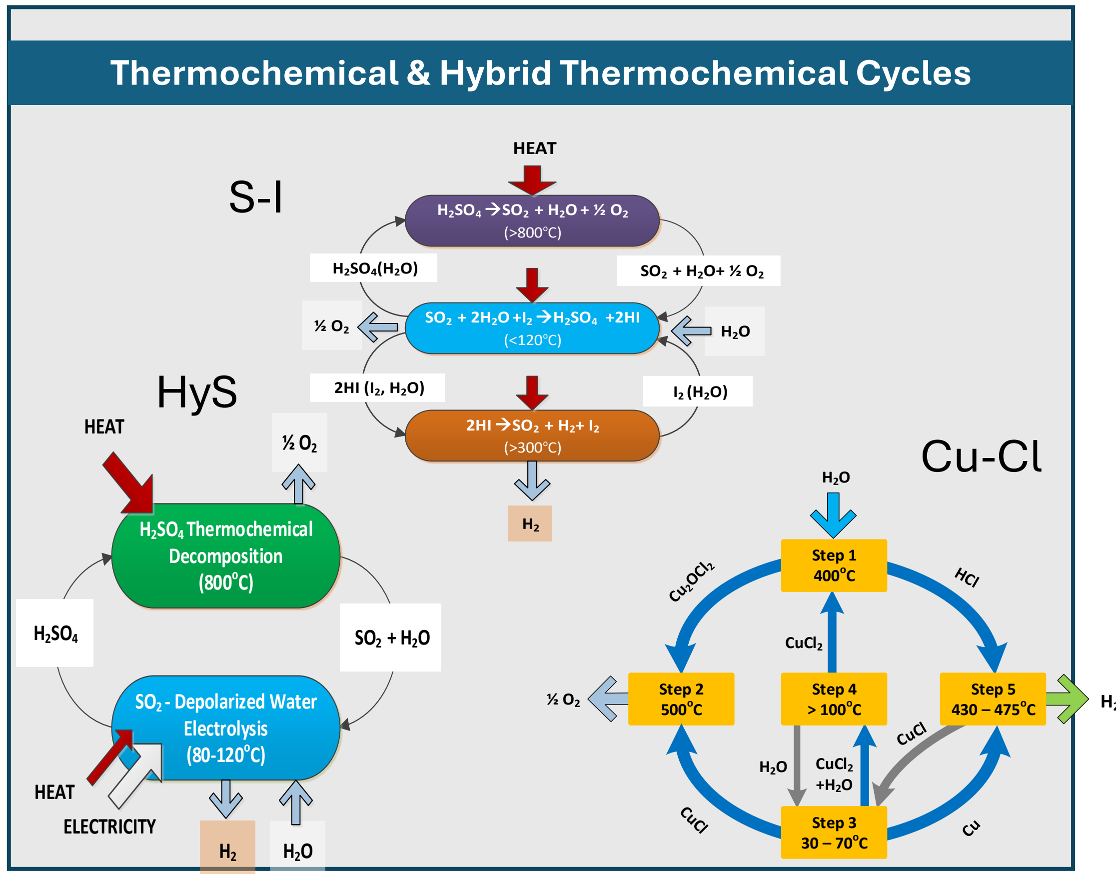
***SCWR**: Super Critical Water Reactor*
***VHTR**: Very High Temperature Reactor*
***SFR**: Sodium cooled Fast Reactor*
***GFR**: Gas cooled Fast Reactor*
***MSR**: Molten Salt Reactor*
***LFR**: Lead cooled Fast Reactor*

Nuclear Hydrogen Production

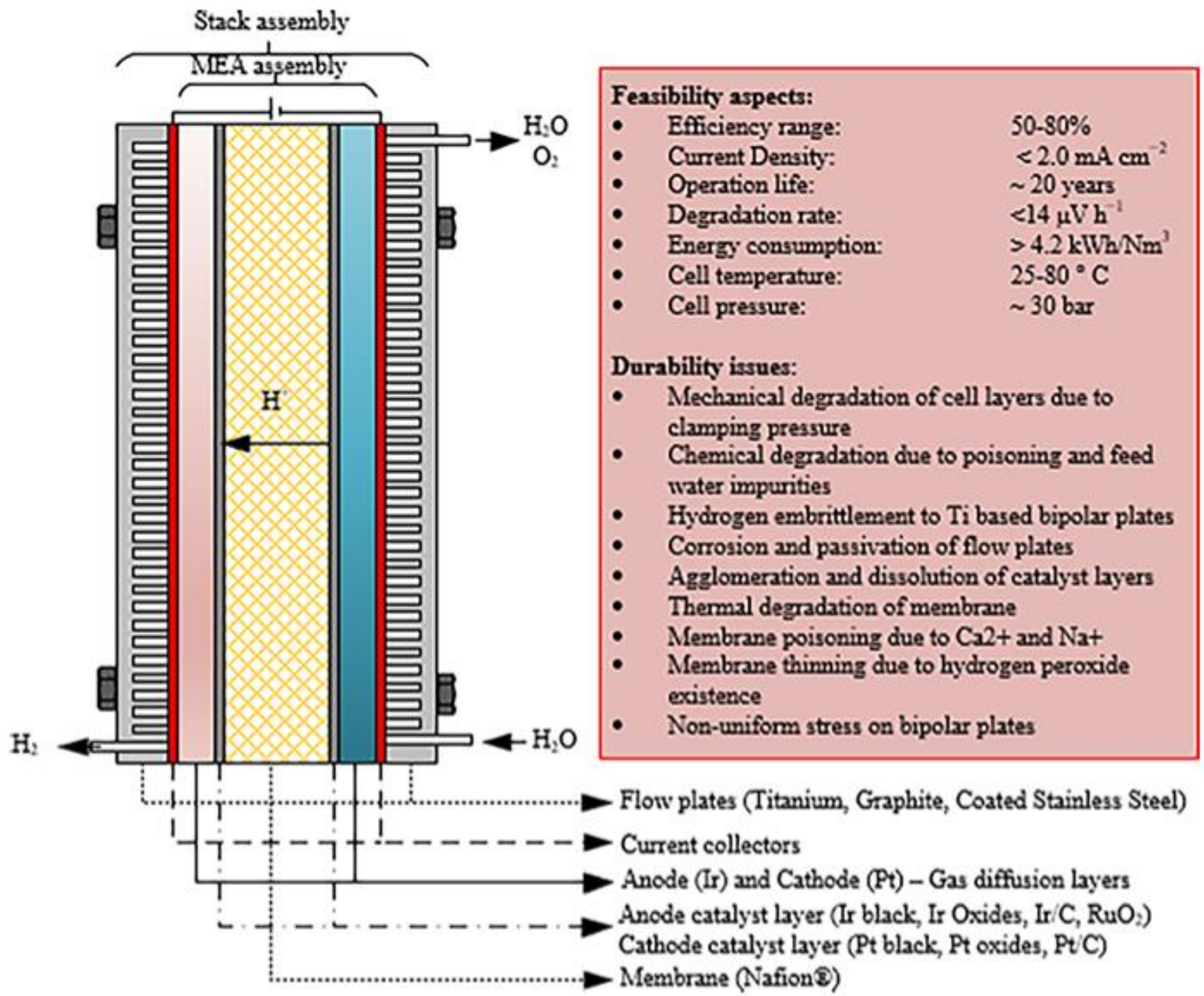
coupling nuclear and hydrogen generation plants would serve in reducing the carbon emissions accompanied with the currently fossil-powered steam methane reforming hydrogen plants.



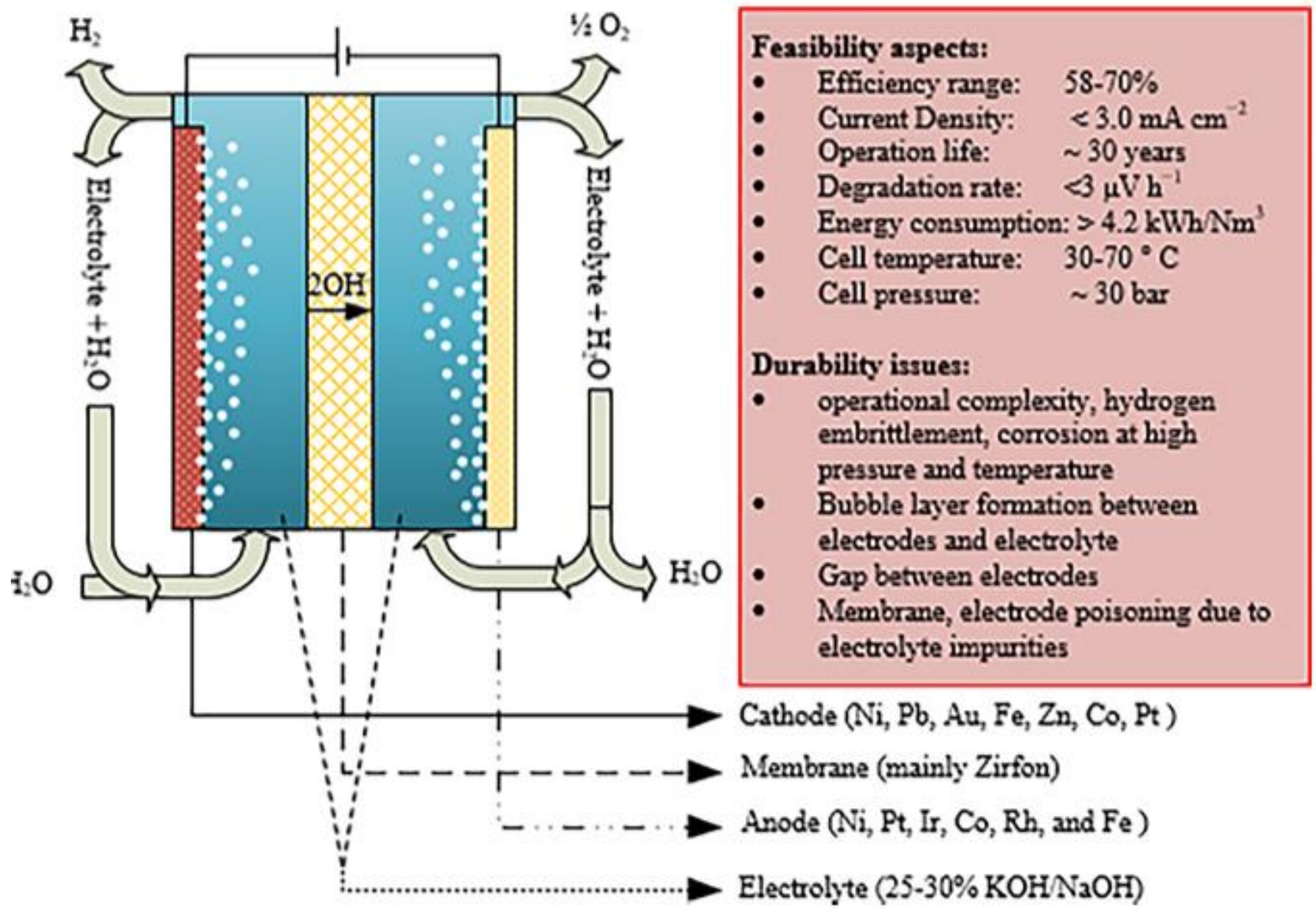




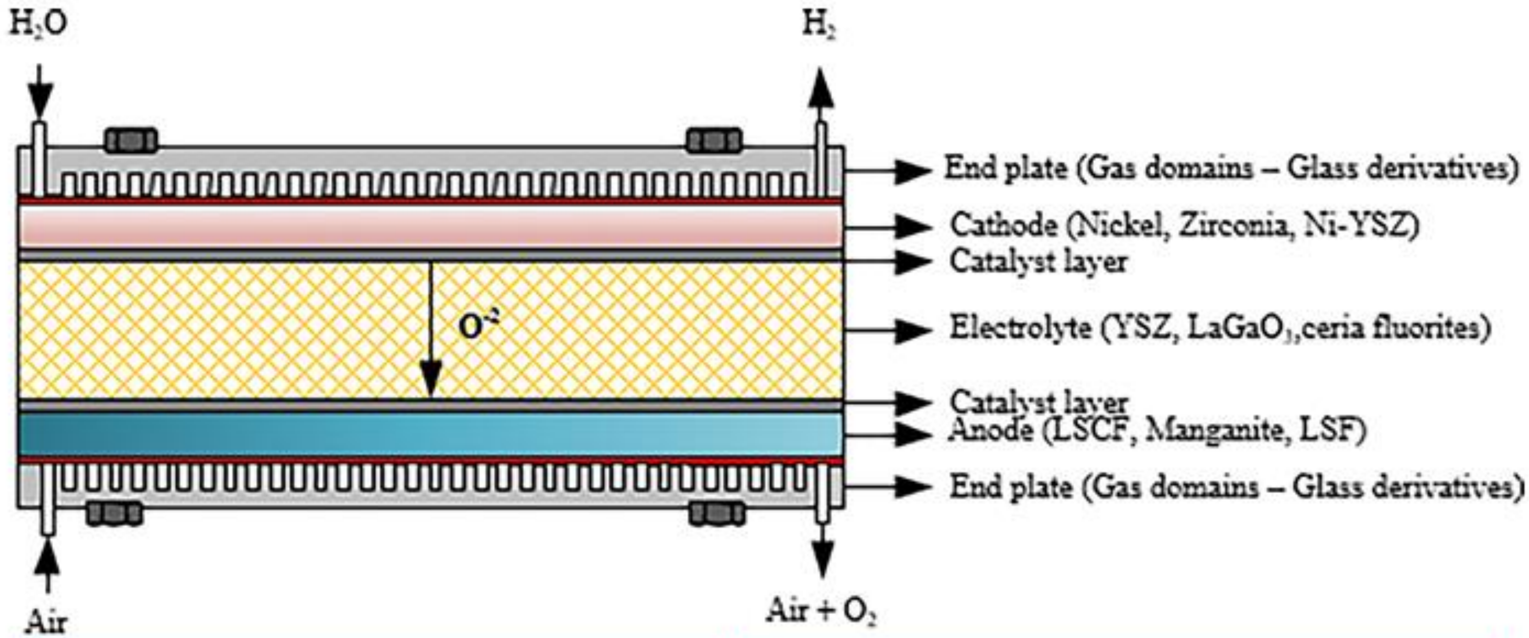
PEM electrolysis



Alkaline Electrolyser



high-temperature steam electrolysis



Feasibility aspects:

- Efficiency range: 70-100%
- Current Density: < 3 mA cm^{-2}
- Operation life: 5-11 years
- Degradation rate: >32 μV h^{-1}
- Energy consumption: 2.9-5.0 kWh/Nm^3
- Cell temperature: >800 ° C
- Cell pressure: ~ 1- 60 bar

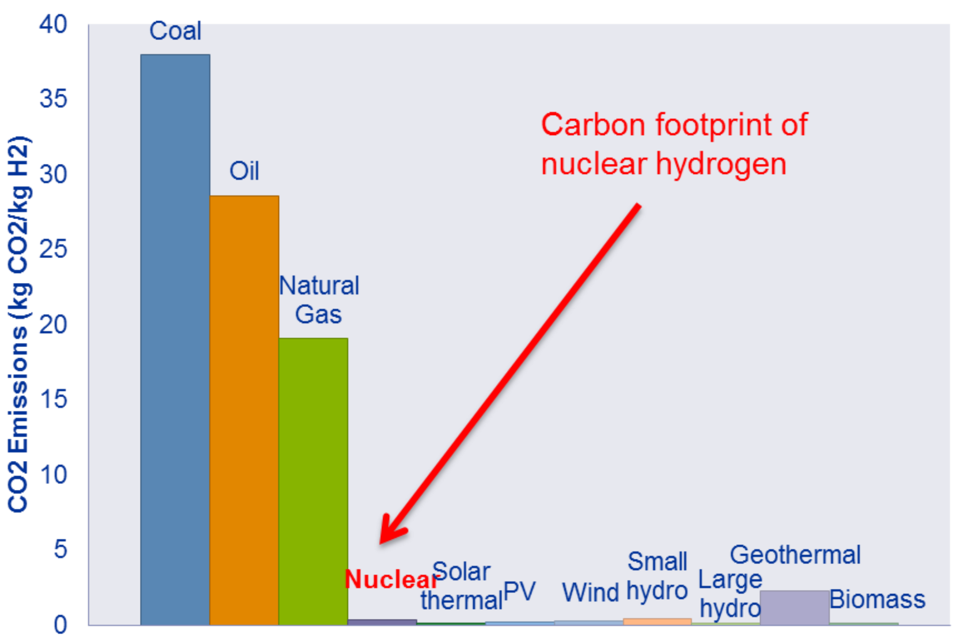
Durability issues:

- Very high degradation rate compared to other electrochemical methods
- Delamination due to high temperature operation
- Pollution on seals and interconnects at stack level
- Sealing leakage due to high temperature operation
- Cell layers posioning due to carbon based sealing materials

Nuclear Hydrogen Production

Driving Forces:

- Replacement of **CO_2** emitting fossil fuels
- Saving of resources by 30-40%
- Securing energy supply by reducing dependency on foreign oil uncertainties



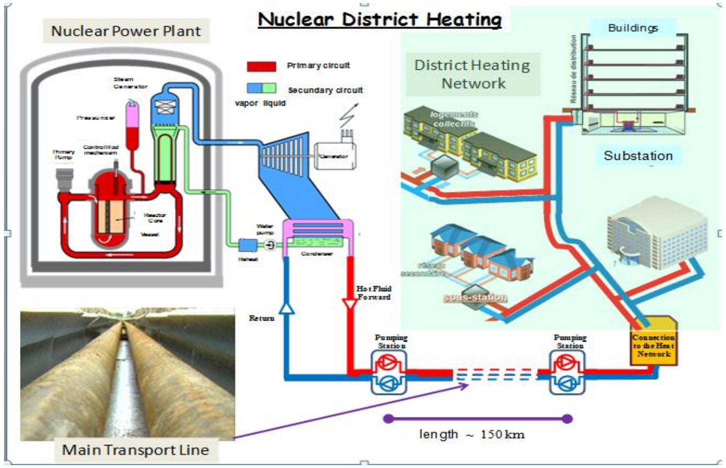
Emissions from ***Nuclear Hydrogen Production!***

Cogeneration for District Heating

- Heat recovery enhances the plant efficiency and provides a high energetic gain (+70%)
- Nuclear heat recovery allows large reduction in CO2 emissions
- Heat transport line can reach long distances (> 100 km)

Recent developments in piping insulation allows transfer of heat for 100 km with only ~ 2% heat loss of the transported power

Cogeneration for District Heating



Heat from NPPs – a contribution to the solution of the CO_2 problem?

Switzerland

Example REFUNA (70 MW_{th}/140GWh_{th}):

- 10 Mio. liter heating oil per year
- savings of more than 26'500 t CO_2
- equivalent to the CO_2 emissions of about 12'000 cars every year

Loviisa 3 CHP – technical data

Finland

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

Russian Federations

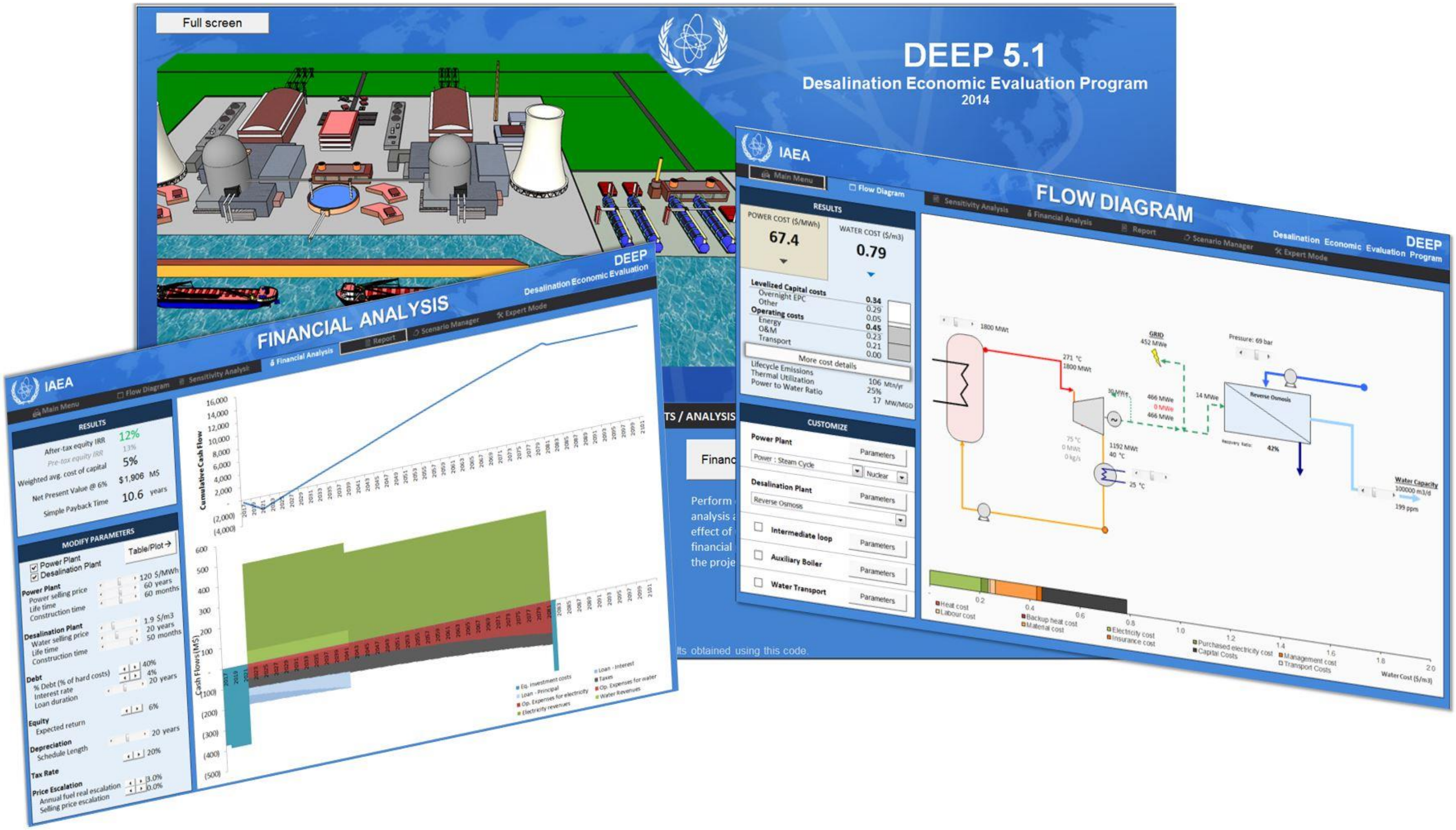
NPP	Thermal Power, MW	Electric Power, MW	Heating capacity, MW
Beloyarskaya	1 470	600	260
Balakovskaya	12 000	4 000	920
Volgodonskaya	6 000	2 000	460
Novovoronezhskaya	5 750	1 880	250
Kurskaya	12 800	4 000	700
Smolenskaya	9 600	3 000	520
Kalininskaya	9 000	3 000	420
Leningradskaya	12 800	4 000	700
Kolskaya	5 500	1 760	145
Bilibinskaya	**248**	**48**	**90**

IAEA Tools and Toolkits
on Cogeneration and Non-Electric Applications of Nuclear Energy

- Desalination Economic Evaluation Programme
- Desalination Thermodynamic Optimization Programme
- Hydrogen Economic Evaluation Programme
- Nuclear Desalination Toolkit
- Nuclear Hydrogen Production Toolkit

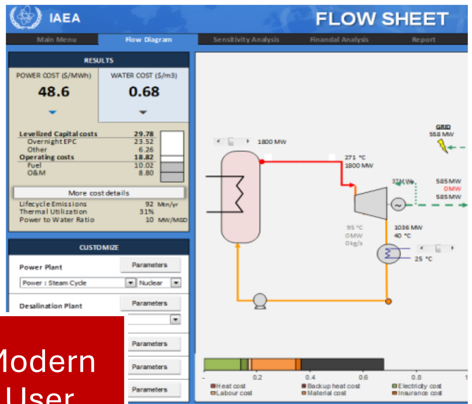
DEEP

performance and cost evaluation of various power and seawater desalination cogeneration configurations.

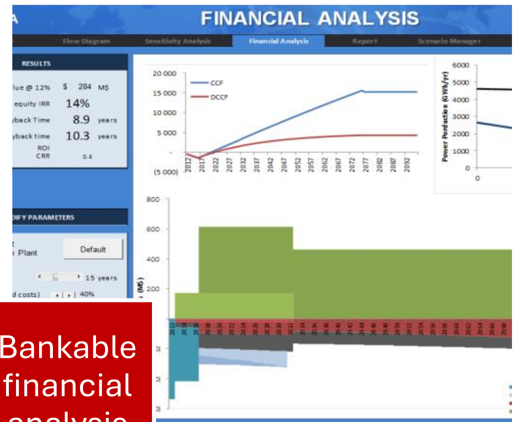


Desalination Economic Evaluation Programme

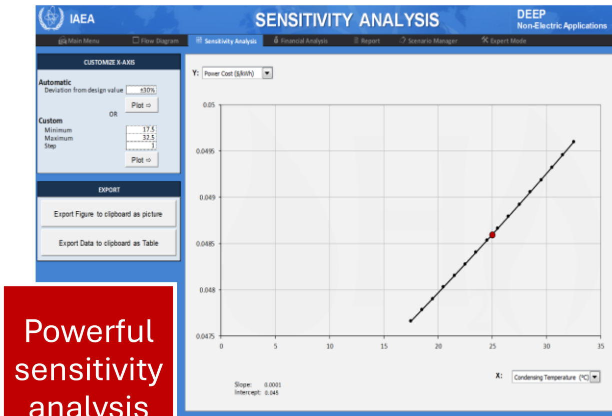
DEEP



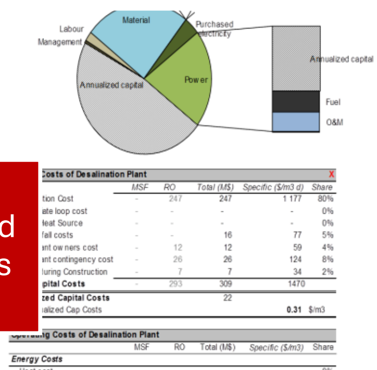
Modern User Interface



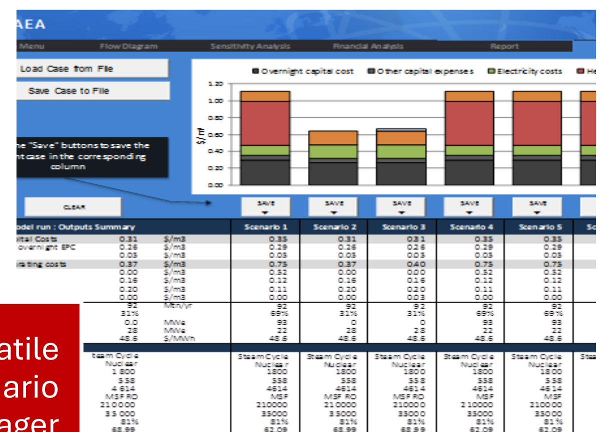
Bankable financial analysis



Powerful sensitivity analysis



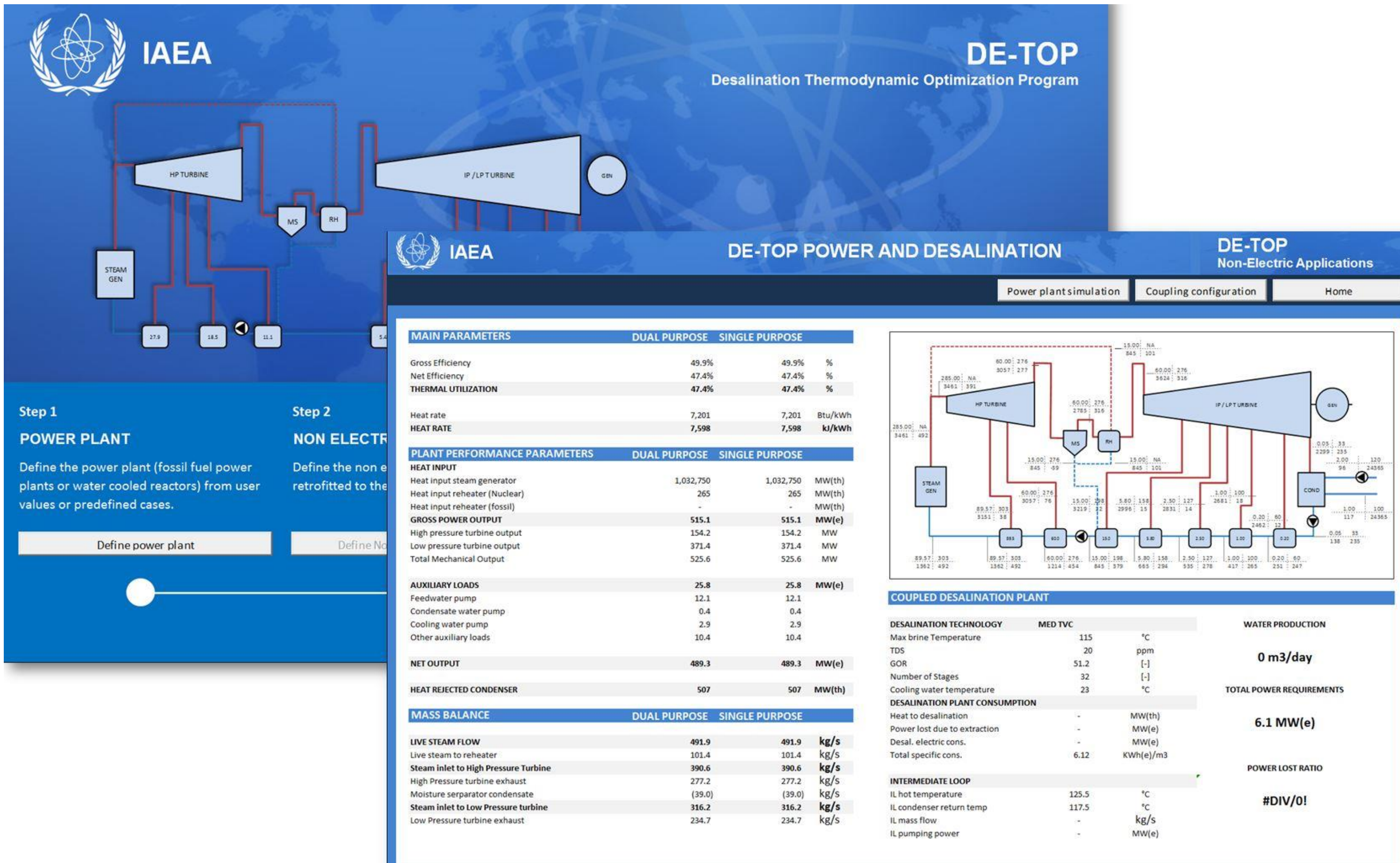
Detailed Reports



Versatile scenario Manager

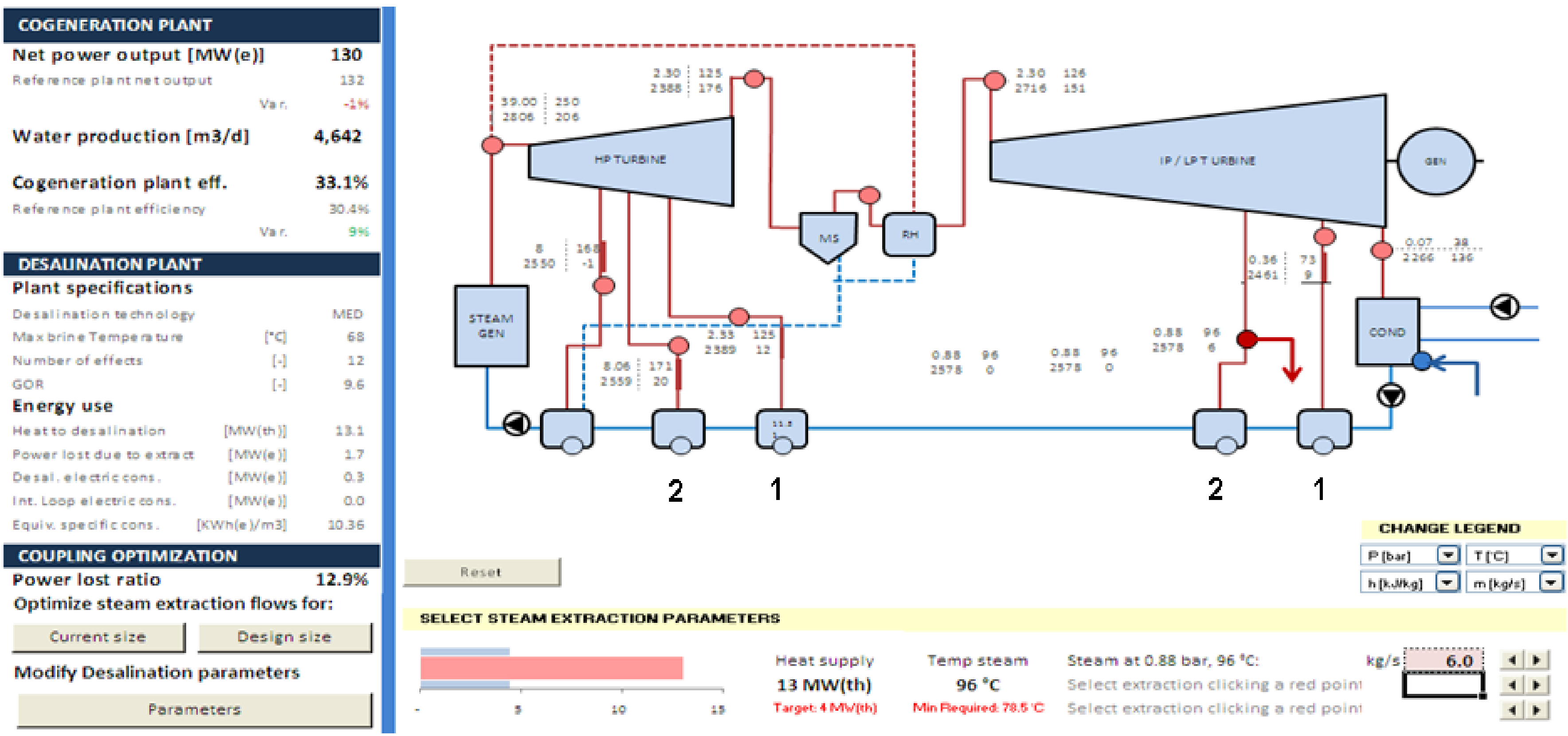
DE-TOP

models the steam power
cycle of different WCRs
coupled with nonelectrical applications



Desalination Thermodynamic Optimization

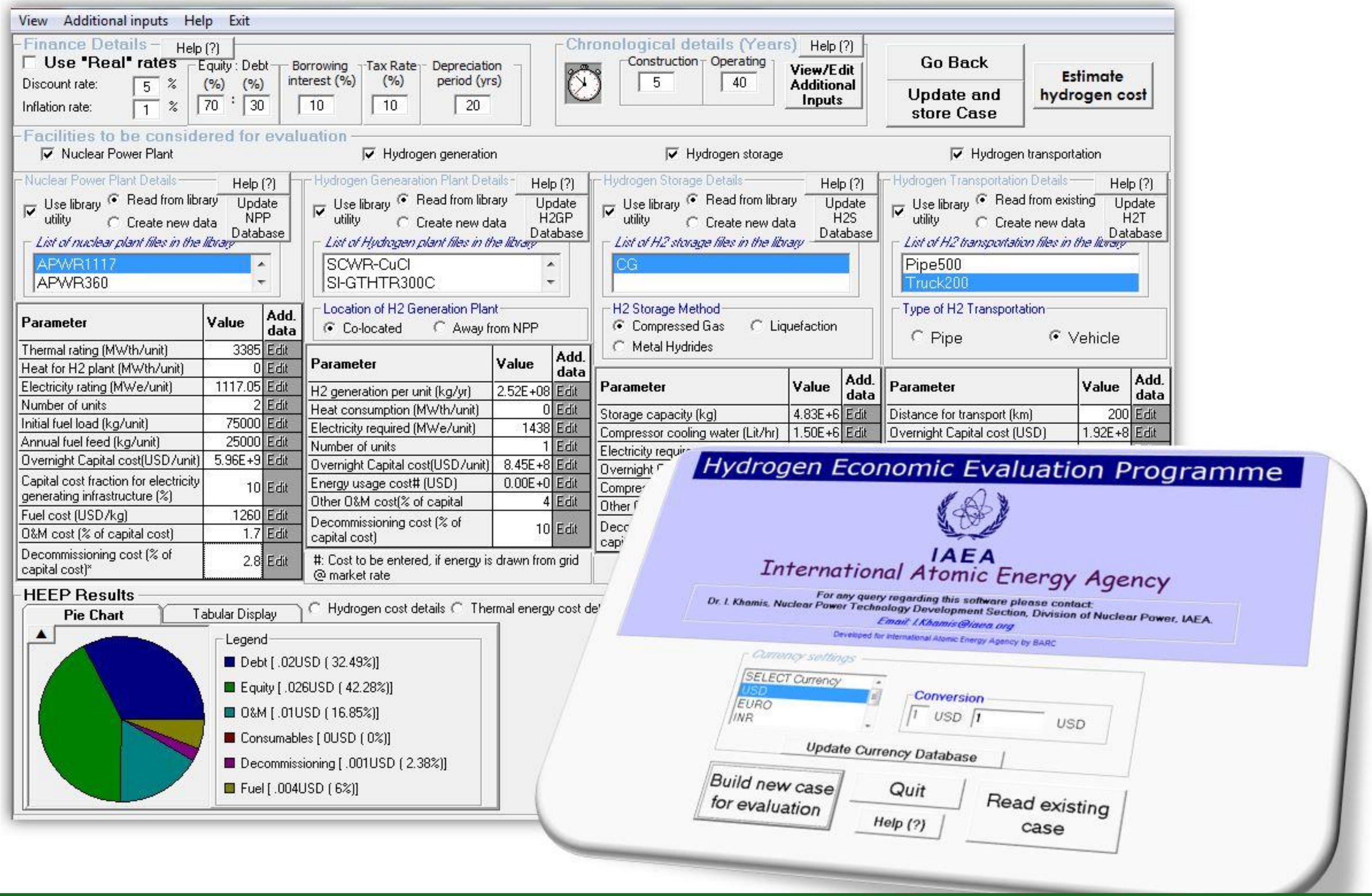
DE-TOP



COGENERATION PLANT
Net power output [MW(e)] 130
Reference plant net output 132
Var. -1%
Water production [m3/d] 4,642
Cogeneration plant eff. 33.1%
Reference plant efficiency 30.4%
Var. 9%
DESALINATION PLANT
Plant specifications
Desalination technology MED
Max brine Temperature [°C] 68
Number of effects [-] 12
GOR [-] 9.6
Energy use
Heat to desalination [MW(th)] 13.1
Power lost due to extract [MW(e)] 1.7
Desal. electric cons. [MW(e)] 0.3
Int. Loop electric cons. [MW(e)] 0.0
Equiv. specific cons. [KWh(e)/m3] 10.36
COUPLING OPTIMIZATION
Power lost ratio 12.9%
Optimize steam extraction flows for:
Current size
Design size
Modify Desalination parameters
Parameters
HP TURBINE
IP / LP TURBINE
GEN
MS
RH
STEAM GEN
COND
2
1
2
1
Reset
CHANGE LEGEND
P [bar]
T [°C]
h [kJ/kg]
m [kg/s]
SELECT STEAM EXTRACTION PARAMETERS
Heat supply
13 MW(th)
Target: 4 MW(th)
Temp steam
96 °C
Min Required: 78.5 °C
Steam at 0.88 bar, 96 °C:
kg/s 6.0
Select extraction clicking a red point
Select extraction clicking a red point

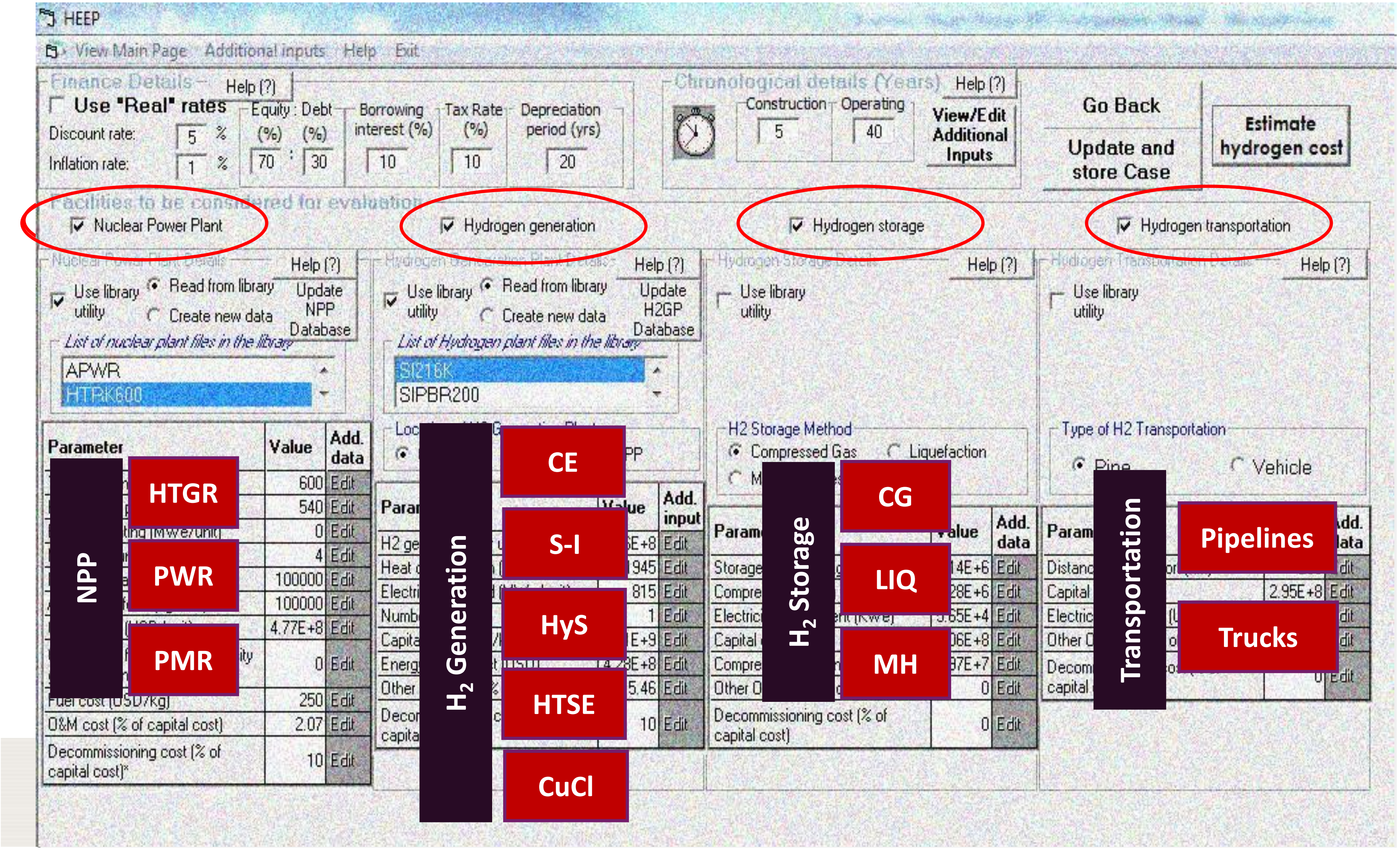
HEEP

Evaluates the economics of the most promising processes for hydrogen production

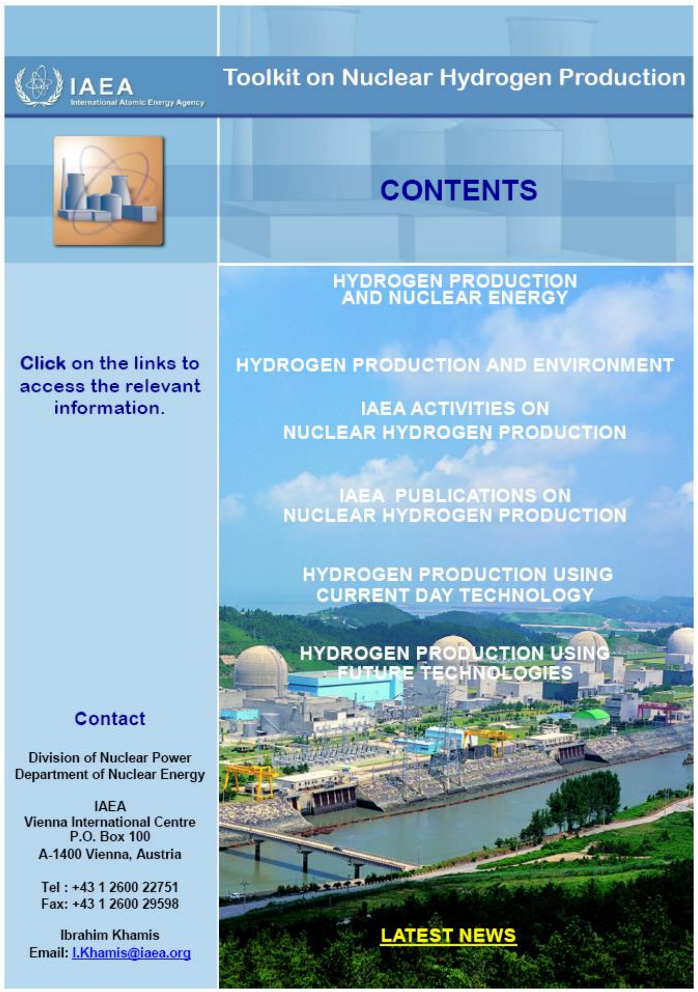


Hydrogen Economic Evaluation Programme

HEEP


HEEP
View Main Page
Additional inputs
Help
Exit
Finance Details
Use "Real" rates
Discount rate:
Inflation rate:
Equity : Debt (%) (%)
Borrowing interest (%)
Tax Rate (%)
Depreciation period (yrs)
Chronological details (Years)
Construction
Operating
View/Edit Additional Inputs
Go Back
Update and store Case
Estimate hydrogen cost
Facilities to be considered for evaluation
Nuclear Power Plant
Hydrogen generation
Hydrogen storage
Hydrogen transportation
Use library utility
Read from library
Create new data
Update NPP Database
Update H2GP Database
List of nuclear plant files in the library
APWR
HTRK600
List of Hydrogen plant files in the library
SI216K
SIPBR200
H2 Storage Method
Compressed Gas
Liquefaction
Type of H2 Transportation
Pipe
Vehicle
Parameter
Value
Add. data
Fuel cost (USD/kg)
O&M cost (% of capital cost)
Decommissioning cost (% of capital cost)*
Decommissioning cost (% of capital cost)
NPP
HTGR
PWR
PMR
H2 Generation
CE
S-I
HyS
HTSE
CuCl
H2 Storage
CG
LIQ
MH
Transportation
Pipelines
Trucks

Nuclear Hydrogen Production Toolkit - NPTDS



- Up-to-date information
- Link to IAEA tools
- Highlights of IAEA Publications
- News on IAEA Activities
- Newsletter on nuclear hydrogen production

Nuclear Desalination Toolkit - NPTDS

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- Summaries of the TWG-ND
- Newsletter on nuclear desalination

Thank you!