International Atomic Energy Agency

Non electric applications of nuclear reactors

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- Nuclear Desalination
- Hydrogen production
- District heating
- Other industrial applications
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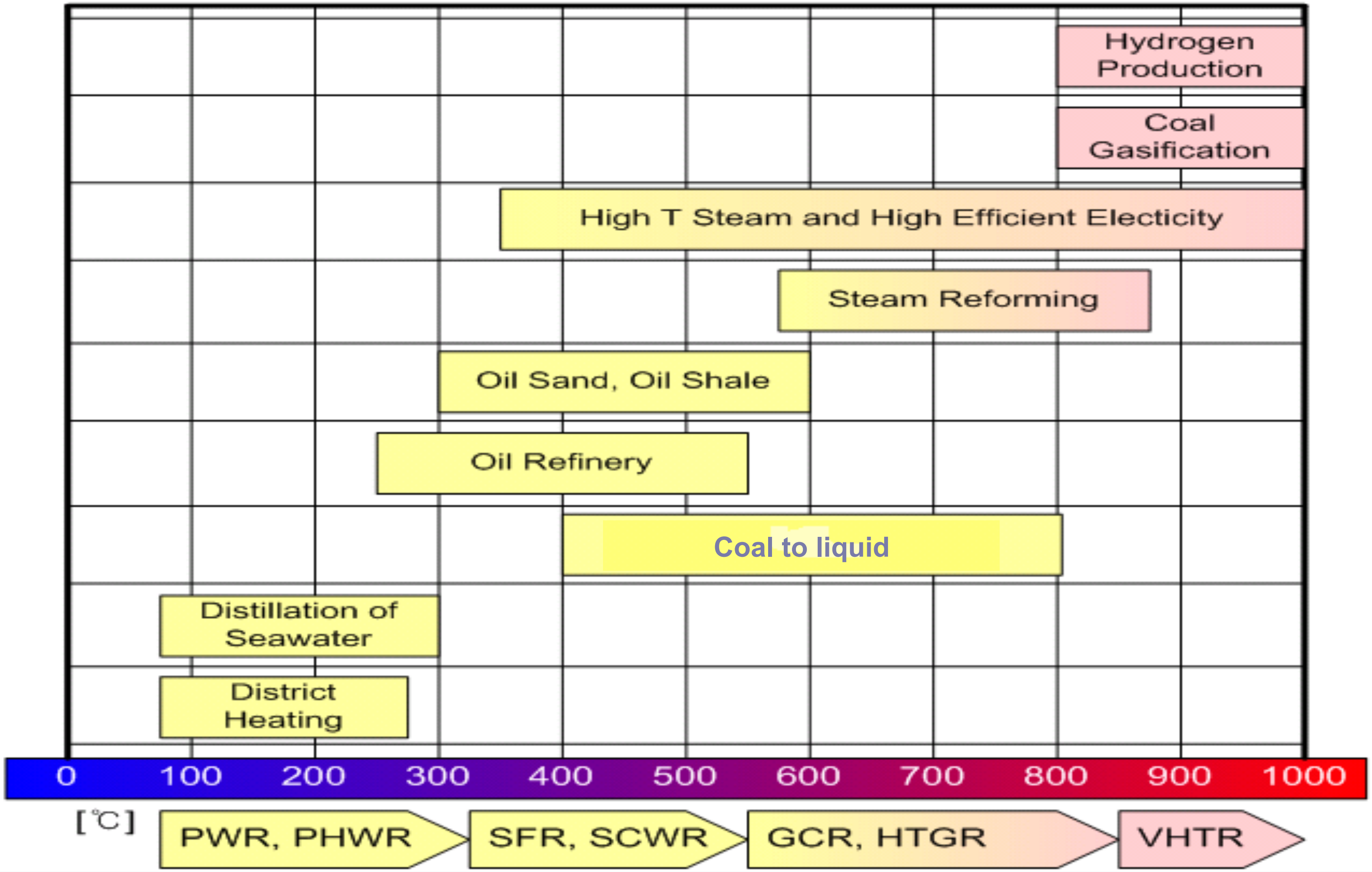
Industrial process vs. temperature

Industrial Process	Approximate Temperature Range (Centigrade)
Home and building heating	100 – 170
Desalination	100 – 130
Vinyl Chloride production	100 – 200
Urea synthesis	180 – 280
Process Steam	200 – 400
Paper and pulp production	200 – 400
Oil refining	200 – 600
Oil shale and oil sand processing	300 – 600
Crude oil desulphurisation	300 – 500
Petroleum refineries	450 –550
Production of synthetic gas and Hydrogen from natural gas or naphtha	400 – 800
Steel making via direct reduction	500 – 1000
Iron industry	600 – 1600
Production of styrene from ethyl-benzene	600 – 800
Production of ethylene from naphtha or ethane	700 – 900
Hydrogen production by thermo-chemical reaction	600 – 1000
Coal processing	400 – 1000
Coal gasification	800 –1000

Nuclear process heat vs. Temperature range



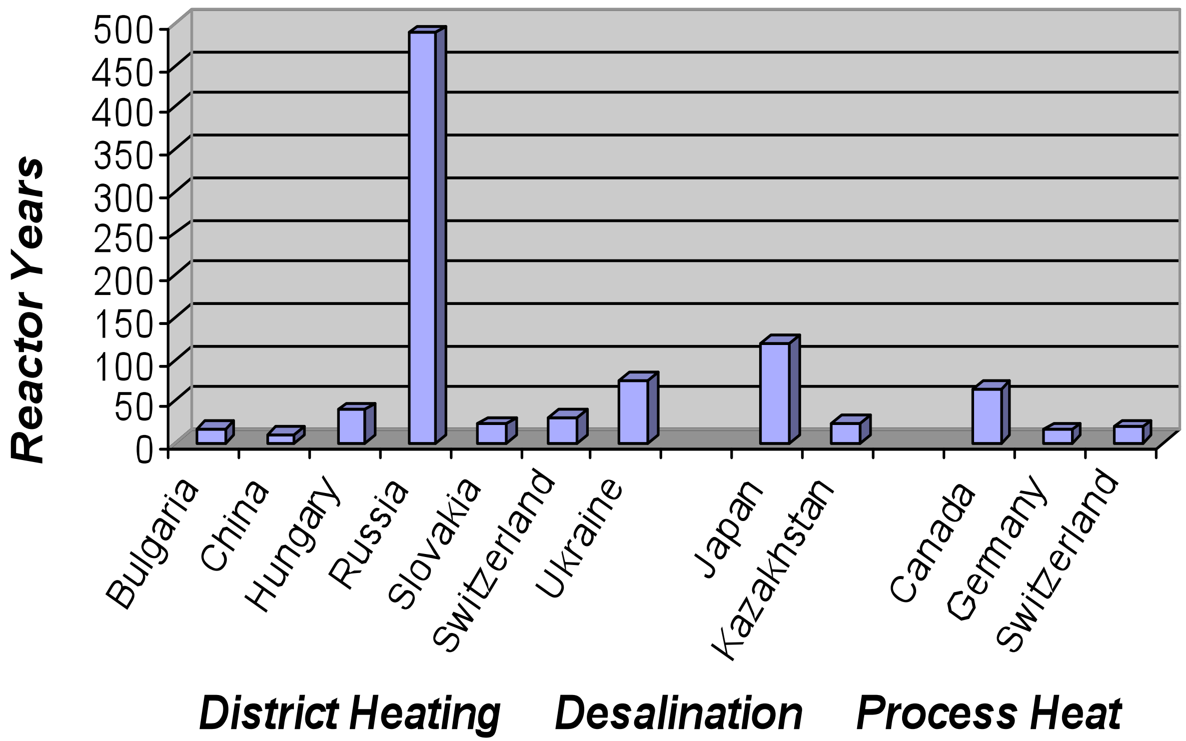
Major non electric applications

- **Nuclear desalination**
- **Hydrogen Production**
- **District heating**
- **Industrial process heat applications**

Non-Electric Applications of nuclear energy

- 14-15% of world electricity is from nuclear power plants
- 438 nuclear power reactors worldwide,
    - 30 are being used for co-generation of hot water and/ or steam for:
        - District heating,
        - Seawater desalination
        - Industrial processes.
- Over 700 reactor-years of combined experience exists for these non-electrical applications.

Operating experience in heat applications



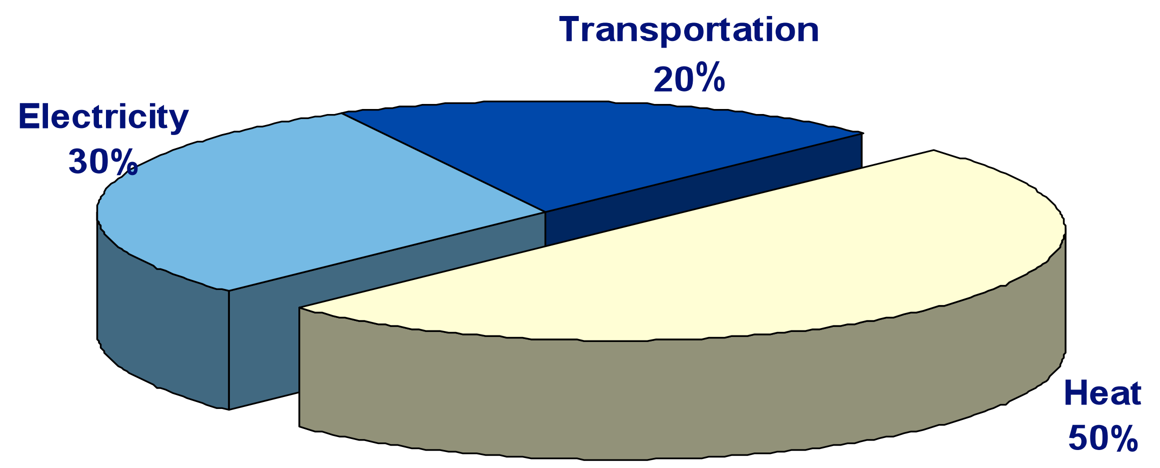
Grouping of non electric applications

- High temperature Process-heat appl.:
  - Hydrogen production & Water splitting
  - Hard coal gasification & refinement of coal and lignite
  - Reforming of natural gas
  - Oil refinery, oil shale &oil sand processing
- Low Temp Process-heat appl.:
  - Steam injections
  - Desalination & district heating
  - Agro-industry

World energy use

Fuel	*Percentage (%)*	*Present trends*
Oil	39	Short-term: Building of additional plants continues
Coal	25	Building of additional plants continues
Gas	22	Short-term – Building of additional plants continues; gas turbine combined cycle plants considered the cheapest of fossil fuelled plants.
Hydro	7	Building of dams continues, where possible
Nuclear	6	Currently under reconsideration in developed countries, with a hope for renewed interest; high rate of expansion in emerging countries.
Renewable energies	1	Gradual expansion; continued efforts to reduce costs.

Energy consumption by application



Total heat capacity of 30 co-generation plants is

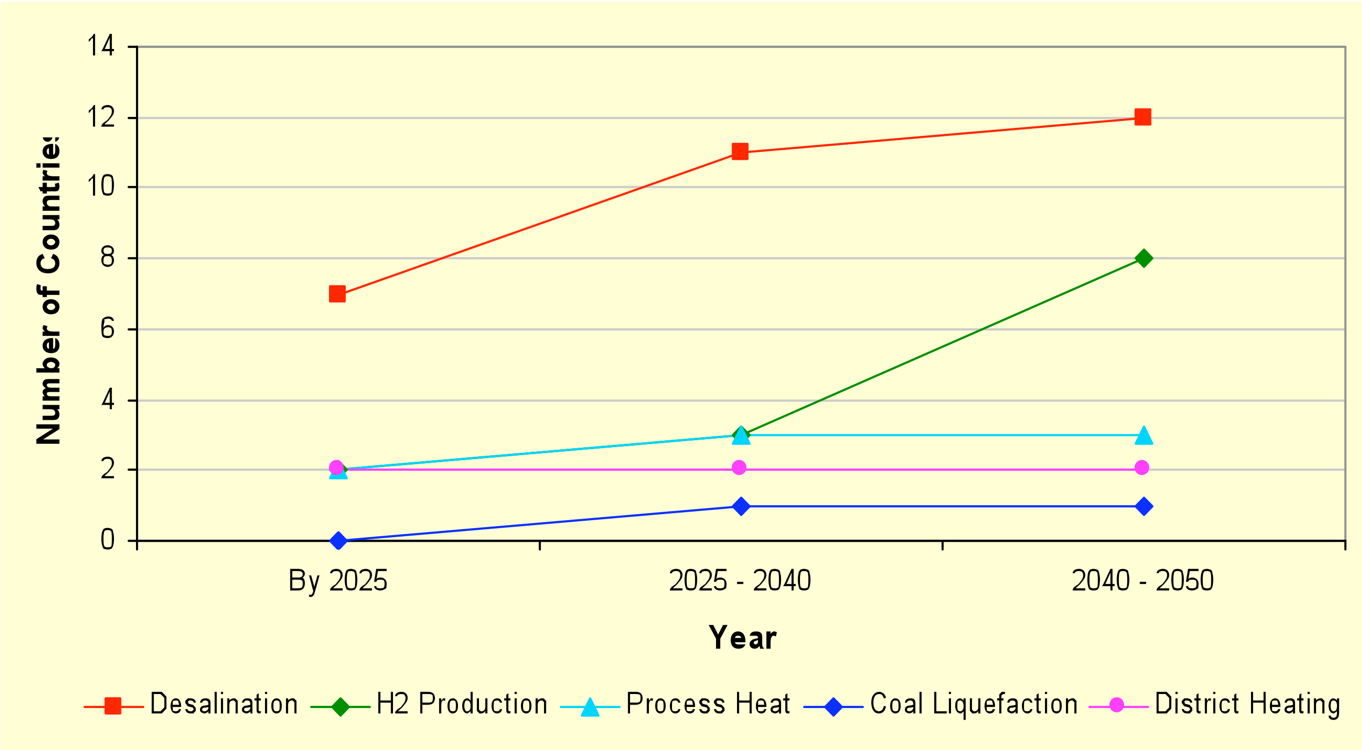
5 GW(th).

Nuclear could make bigger impact by penetrating heat and transportation sectors

Prospects of non electric applications

- ***Current and near term*** **applications using currently available nuclear reactors.**
  - **Desalination, with emphasis on *cogeneration***
  - **District heating**
  - Steam for industrial applications including heavy oil recovery
  - "Plug-in" hybrid electric vehicles using electricity
  - Hydrogen production (using electricity and heat)
- ***Mid term*** **applications using HTR**
  - **High-temp process heat appl**
  - **Hydrogen production**
  - **Other appl.**

Prospects for Non-Electric application

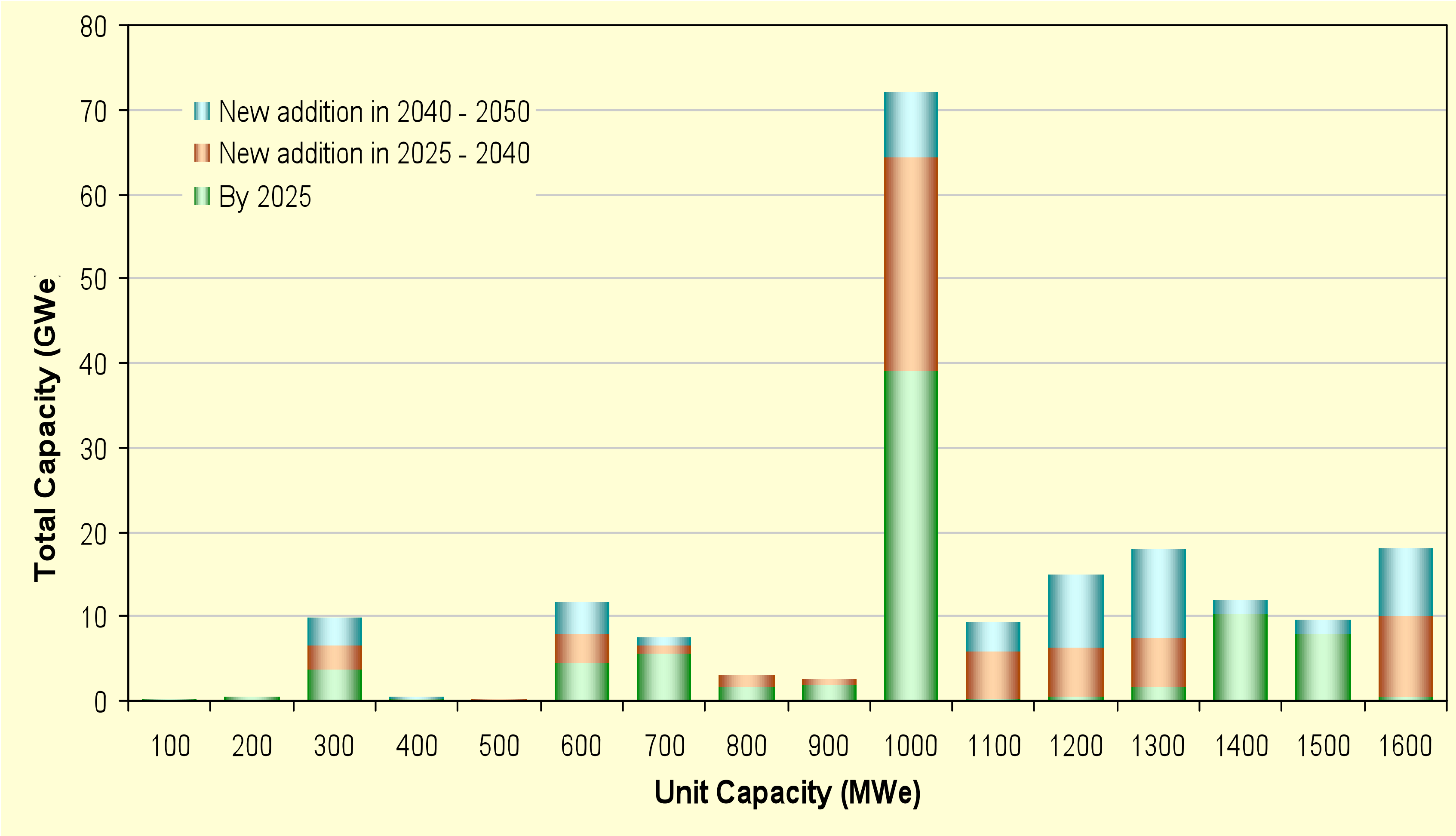


By 2050, desalination and hydrogen production are most preferred cogeneration of NPPs.

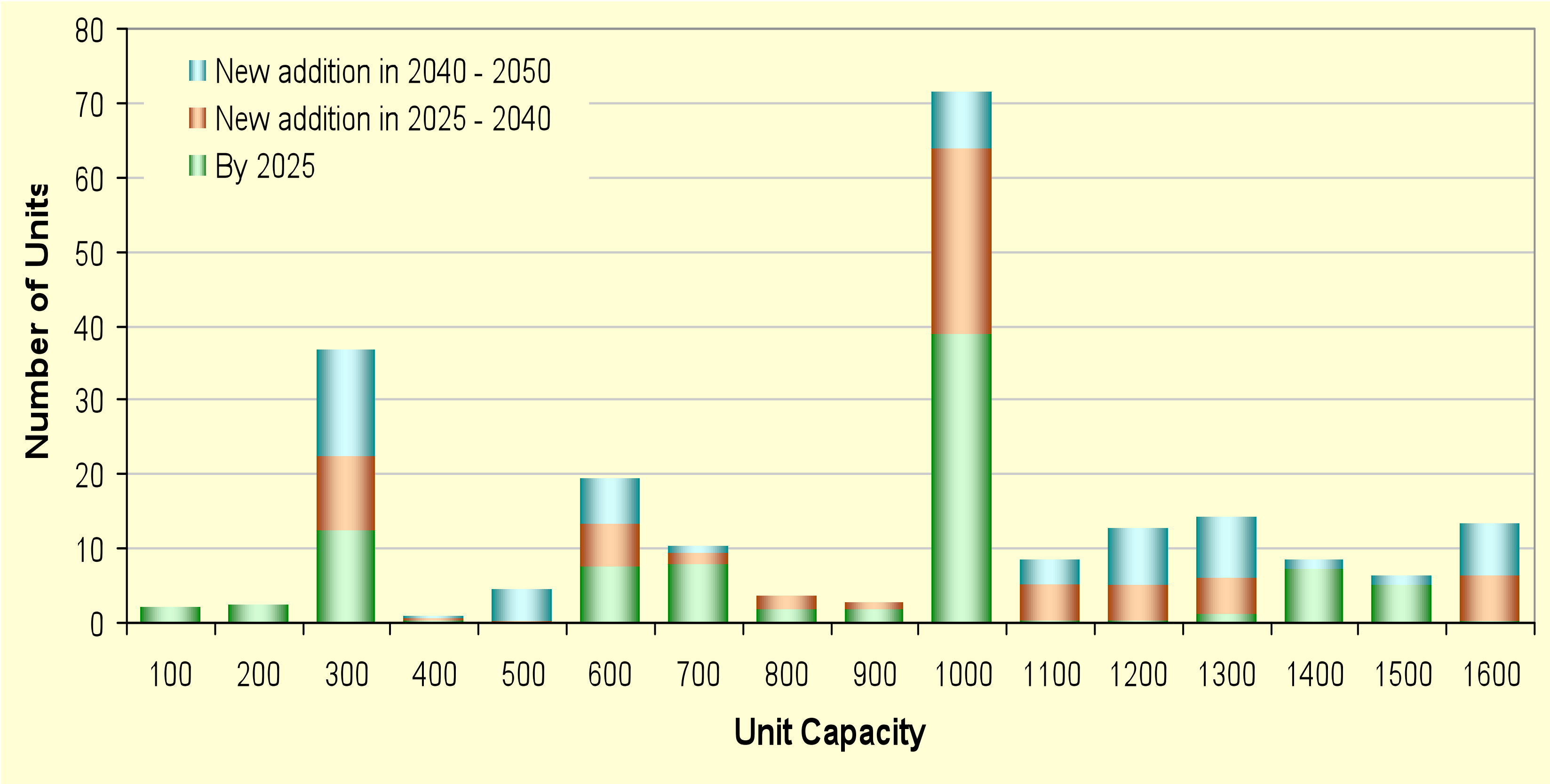
Survey
Expected Non-electricity Application of NPPs

	Number of Countries		
	By 2025	By 2040	By 2050
Desalination	7	11	12
H_2 Production	2	3	8
Process Heat	2	3	3
Coal Liquefaction	0	1	1
District Heating	2	2	2

Total Capacity of New NPPs Expected at Different Sizes



Number of New NPPs Expected at Different Sizes



Number of non-electrical units (Age is based on exploitation start date)

Statistics criteria	Groups & Sections
Base Year = 2000 (Operational in Base Year OR Shutdown in Base Year)	Group by Type

Type	No. of Units
DH – District Heating	19
DS – Desalination	6
PH – Process Heating	9
	34

Hydrogen Demand

Hydrogen Main Consumers

World H_2 production per year ≅ 500 billion Nm^3

Equivalent energy ⇒ ≅ 1.5% world energy consumption (≅ 75000 MWe equivalent converted electric power)

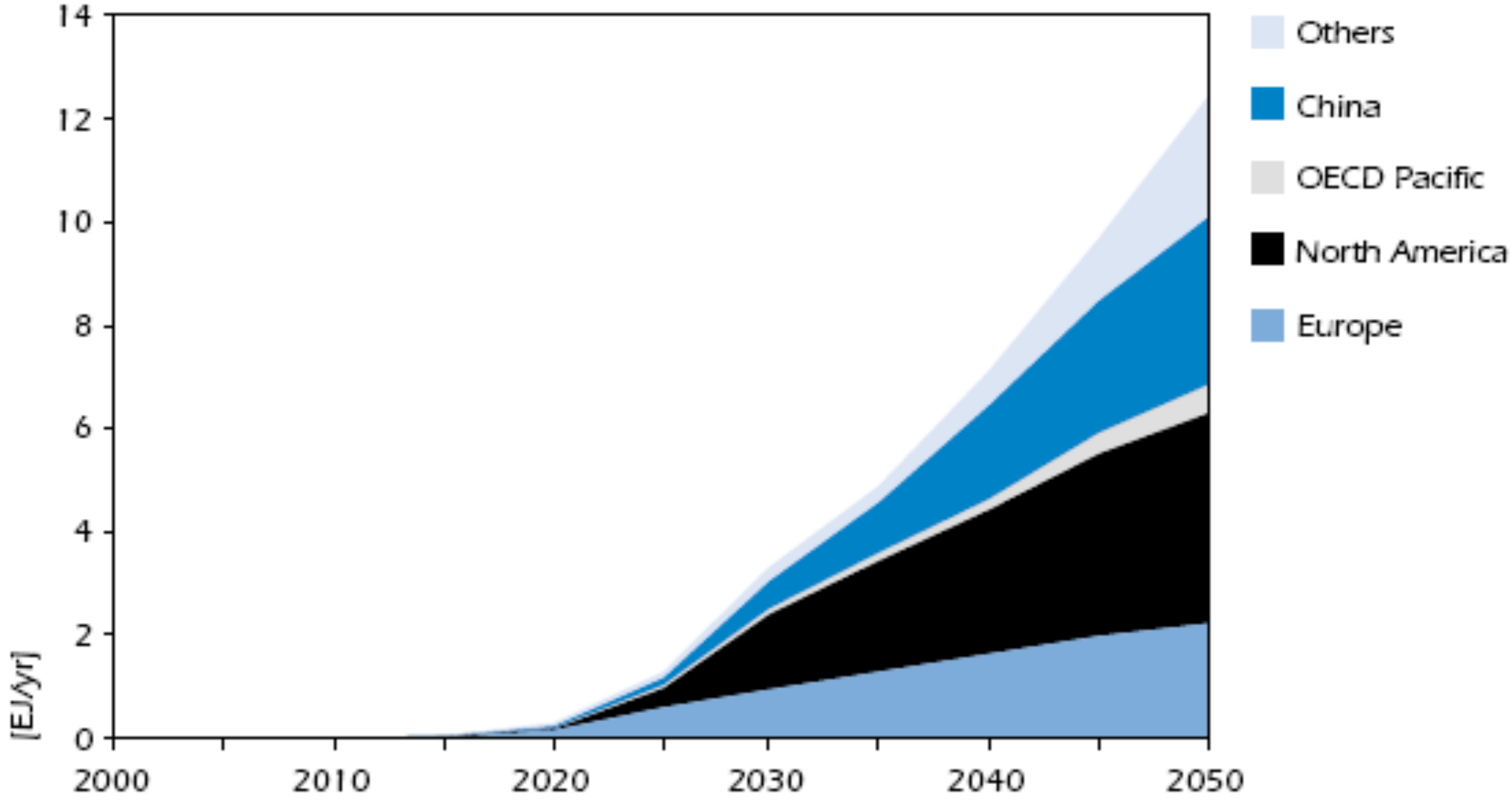
Raw material used ⇒

Uses of hydrogen ⇒

- 50% is used in fertilizer production (Ammonia)
- 37% is used in refining processes with a tendency to increase due to the utilization of heavy oils ≅ 200 billions Nm^3 per year
- 8% is used in methanol production
- 1% is used in space programmes
- 4% others

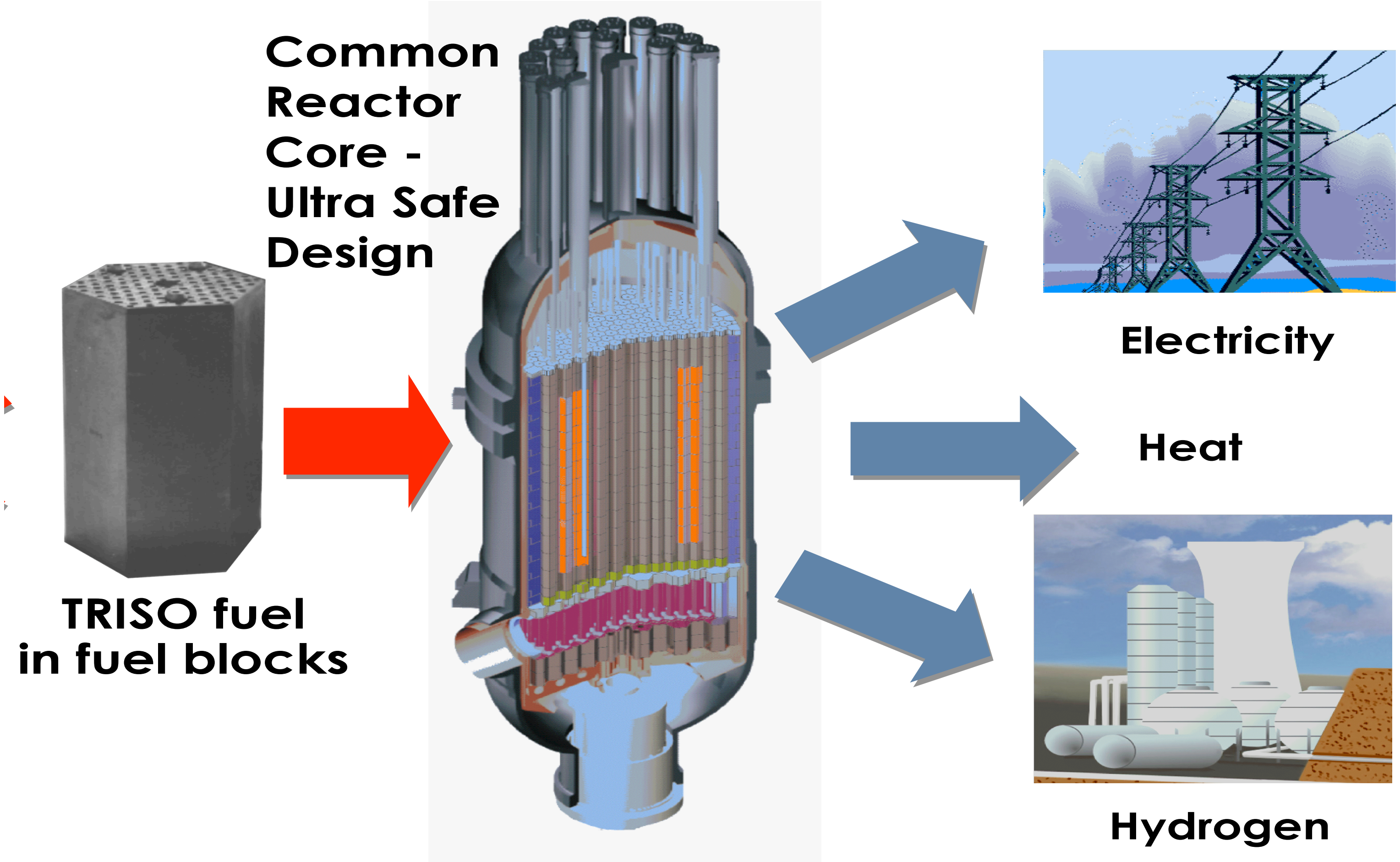
Hydrogen Demand

Future of the Hydrogen demand by region



Source: Hydrogen demand, production and cost by region to 2050 (ARGONNE National Laboratory)

Nuclear hydrogen production



Nuclear energy and hydrogen

Nuclear energy:

- **Has been used mainly for electricity generation (more than 12000 years of reactor operation).**

- **Can play a significant role in areas of non electric applications like: hydrogen production, desalination, district heating, and other industrial applications.**

- **Still has only a small share of the non-electric application market.**

Advantages of using nuclear energy for hydrogen

- Reduction of Co2 to minimal rate.
- Low nuclear fuel cost will result in low cost of hydrogen production.
- Use of off-peak electricity for hydrogen production.
- Offers high temperature coolant in some specific cases like HTGR and VHTR.
- Offers better efficiencies for H-production.

Hydrogen Production

- **Decomposition and gasification of fossil fuel:**
  - **Steam reforming of methane (600-800 C).**
  - **Carbon dioxide reforming of methane (800-900 C).**

- **Decomposition of Water:**
  - **Thermo-chemical Water Splitting (above 900 C).**
  - **Electrolysis:**
    - **Low-temperature (below 100 C).**
    - **High-temperature (above 800 C).**

Advances in HTR → *Increased interest in Hydrogen economy*

Nuclear hydrogen

- There is an ***increased interest*** in hydrogen as a carbon-free fuel of future.
- Demand for hydrogen is large and keeps growing (at rate of 4-10 % /year).
- Reforming of hard coal and oil (gasification): 96% of the annual hydrogen production

Characteristics of hydrogen production

- Promising
- Still under R&D
- Safety of coupling is still an issue of concern
- Cost of under development processes (thermochemical cycles & High temperature electrolysis) will be <u>a major factor</u>

CHALLENGES FOR NUCLEAR HYDROGEN PRODUCTION

- Technology
  - Materials selection for long term operation (corrosive, high temperature environment)
  - Process system design, control and integration
  - Demonstration of production processes at large scale
  - Development of storage systems (e.g. 350-700 bar) due to H_2 low energy density
- Safety
  - Coupling of H_2 production plant with NPP
    - Preventing H_2 migration
    - Preventing H_2 combustion

CHALLENGES FOR NUCLEAR HYDROGEN PRODUCTION

- Economics
  - Demonstrating low H_2 production costs on an industrial scale
  - Exploiting today's needs to move toward a large future market
  - Building and operating a very large number of NPPs with low energy generation costs (if H_2 is to replace a significant amount of fossil fuel for transportation)
- Public acceptance
  - Both H_2 and NPPs

Hydrogen production using nuclear power

High temperature → High efficiency

- **High Temperature Electrolysis (~ 900 C).**
- **Sulfur-based thermo-chemical cycles for water splitting:**
  - **Using Sulfur- Iodine cycle.**
  - **Hybrid Sulfur cycle.**
  - **Sulfur-Bromine hybrid cycle (with molten salt gas, liquid metals, and).**

High temperature electrolysis using nuclear electricity and heat

Compared to thermochemical cycles:

- Has lower efficiency than thermochemical cycles.
- Low operating temperature resulting in less daunting operating conditions (less corrosive)

- Advantage: Build on existing fuel cell technology .

Electrolysis is promising particularly in the near term future

Hydrogen Production Alternatives

Short-Term Option

Electrolysis

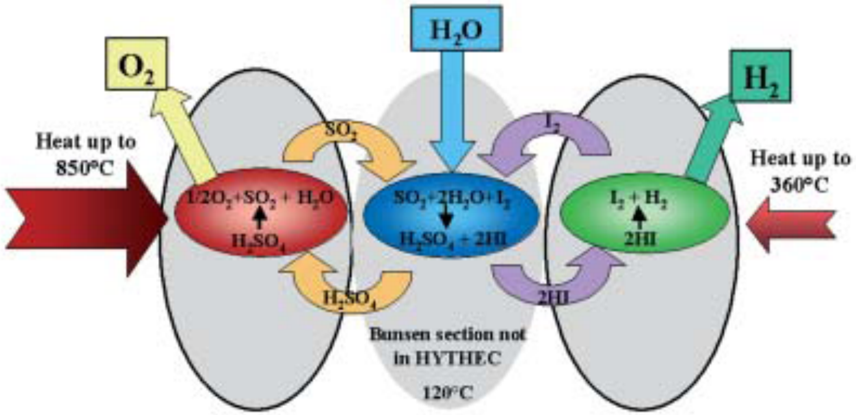
- Electrolysis ideal for remote and decentralized H_2 production
- Off-peak electricity from existing NPP (if share of nuclear among power plants is large)
- As fossil fuels become more expensive, the use of nuclear outside base load becomes more attractive

200 m^3/h

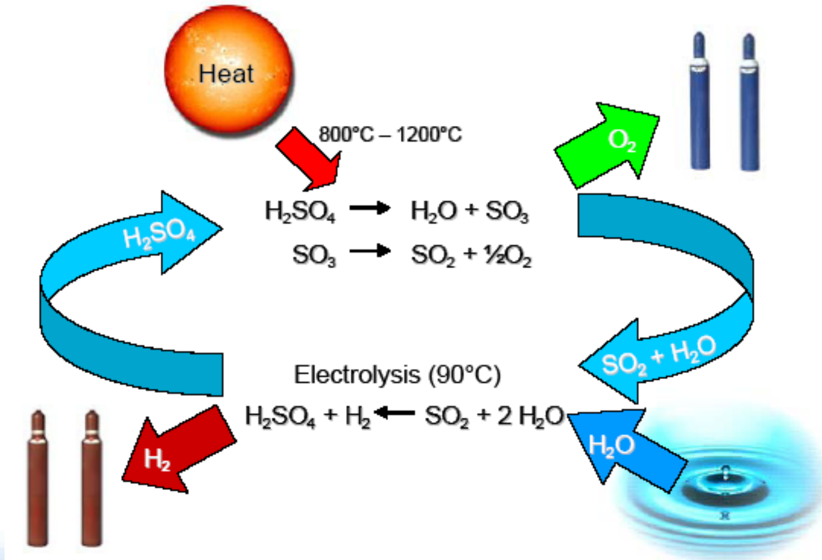
Hydrogen Production Alternatives

Hydrogen Thermochemical Cycles

- Sulphur-Iodine (S_I) cycle

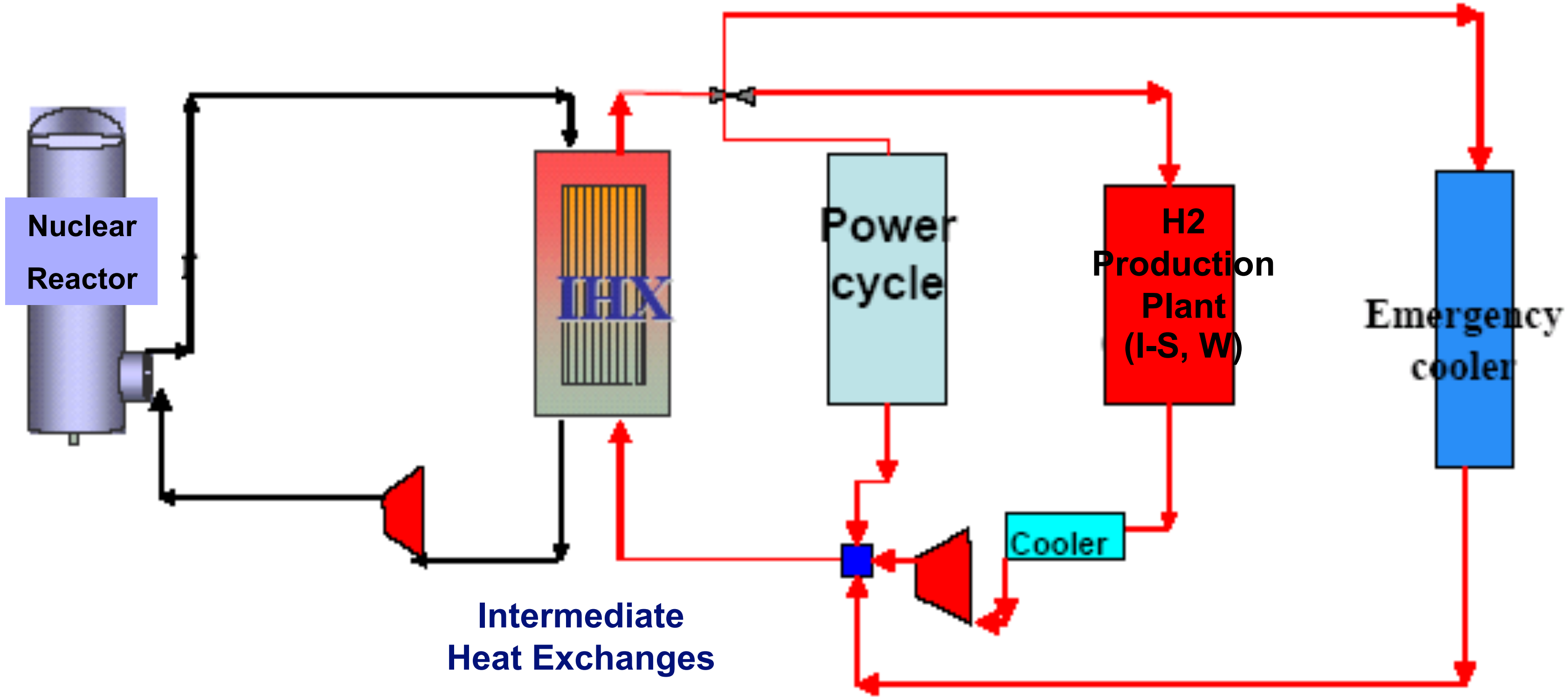


- Hybrid-Sulphur (HyS) cycle.



Nuclear Hydrogen Production

Indirect Self-Sustainable cycle 600 MWth.



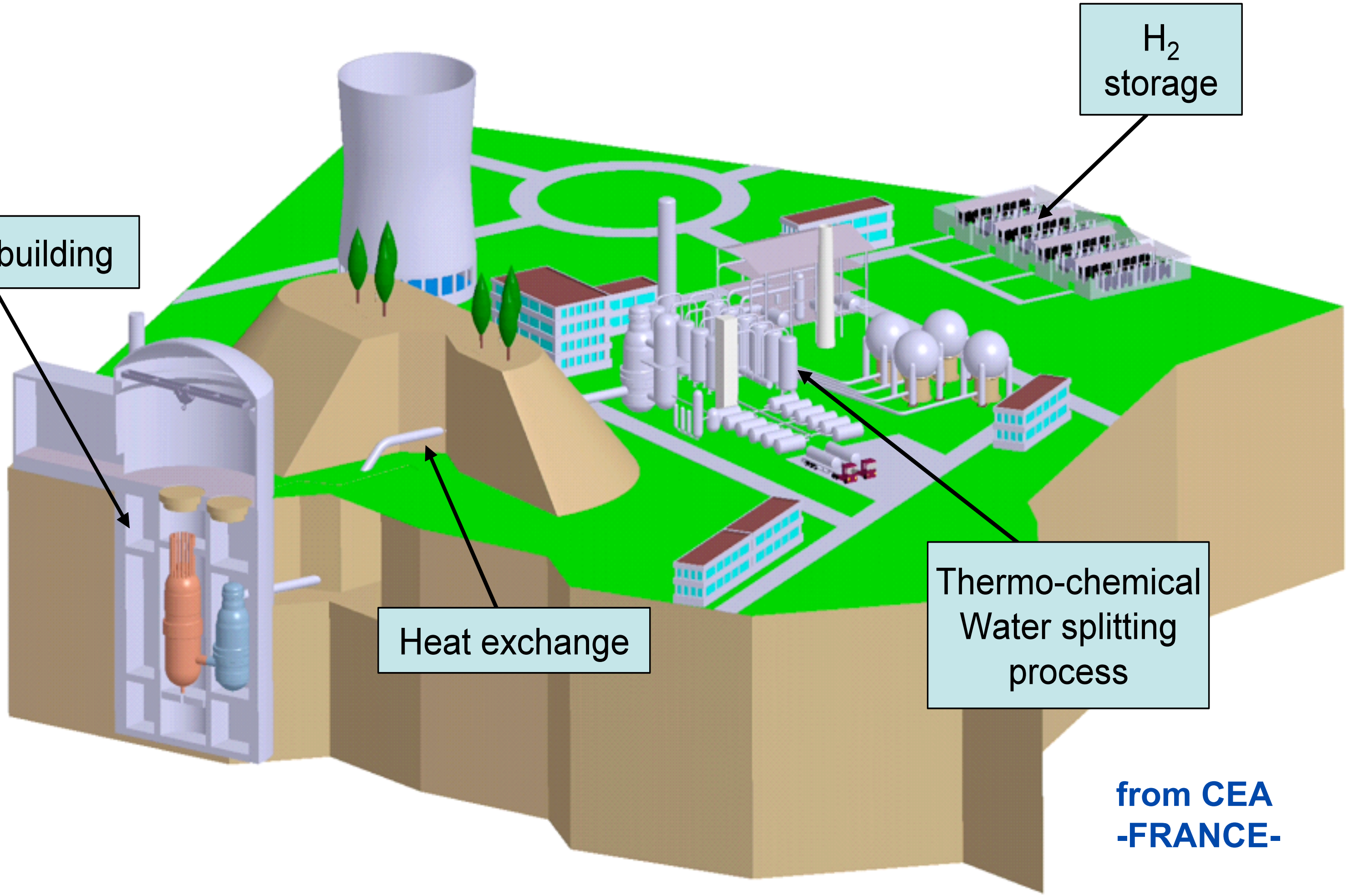
Nuclear

Reactor

Thermal efficiency of the conversion:	48%
Generated electric power:	110 MWe
Thermal power transferred to the cycle:	320 MWth
Hydrogen mass-flow rate:	633 mol H2/s
Hydrogen Production:	110 ton/day

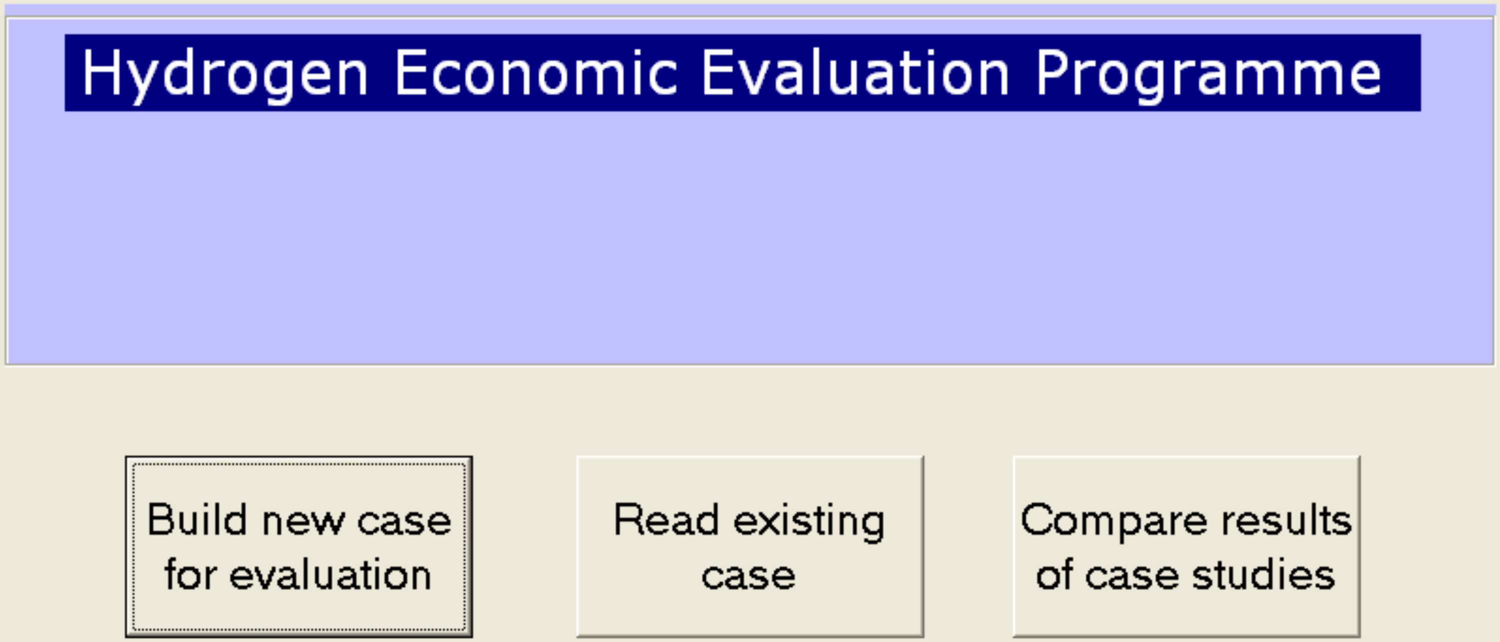
Nuclear Hydrogen Production

Potential Arrangement of 600 MW VHTR for H2 Production



from CEA -FRANCE-

HEEP



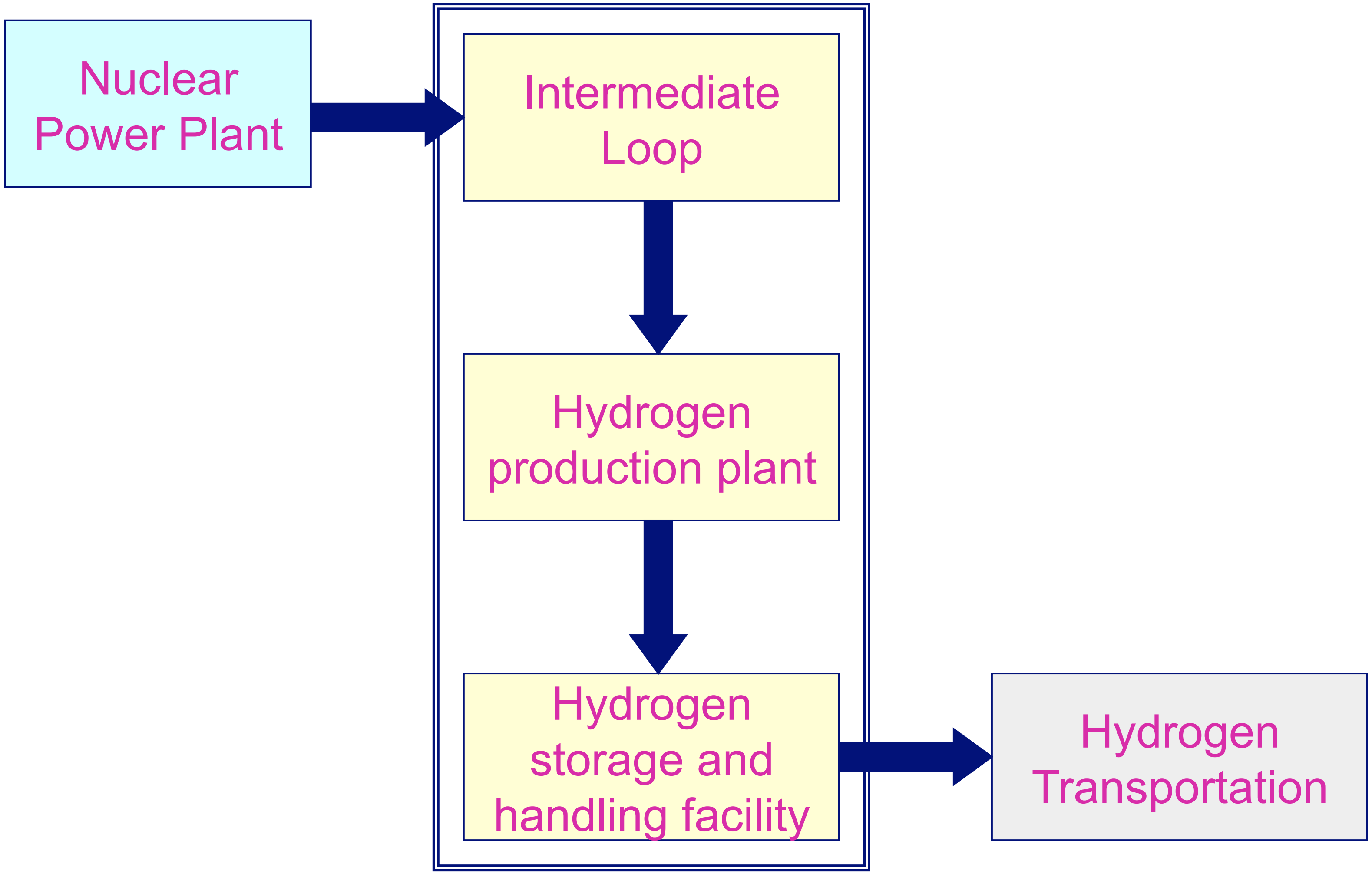
- **User-friendly interface to input, view and edit the data**
- **Similar to IAEA-DEEP (Desalination Economic Evaluation Programme)**
- **Under development by IAEA/Bhabha Atomic Research Centre, Mumbai, India**
- **Goal: Analyze economics of nuclear hydrogen**

HEEP

Inputs to be provided by the user for HEEP:

- **Technical details for:**
  - **Nuclear power plant (NPP),**
  - **Hydrogen generation plant (HGP)**
  - **Hydrogen transportation and dispensation (HTD)**
- **Time schedules of NPP, HGP and HTD**
- **Cost components of NPP, HGP and HTD**
  - **Capital cost**
  - **Cost of fuel in case of NPP**
  - **Cost of consumable**
  - **O&M cost**
  - **Decommissioning cost**

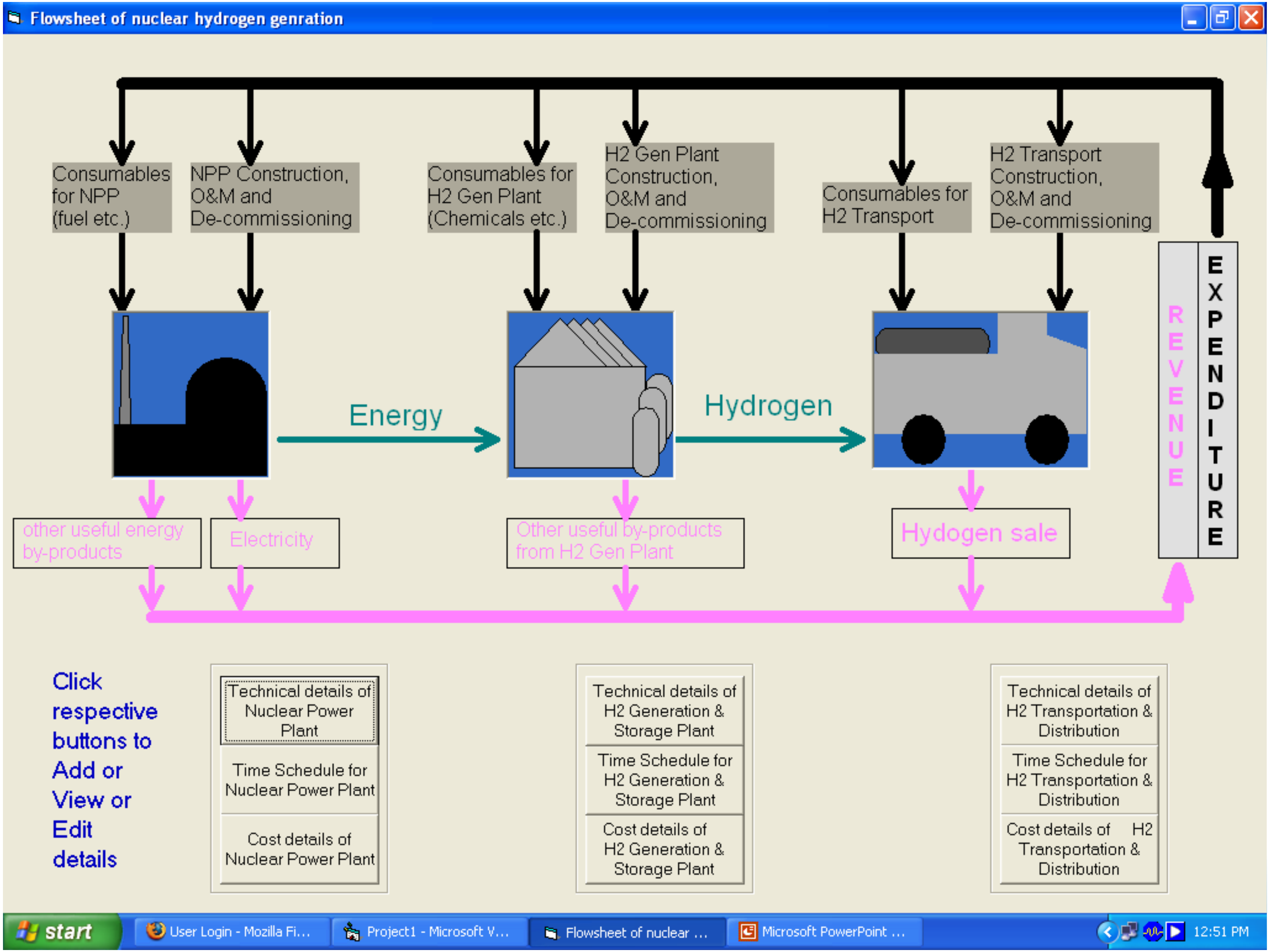
Processes considered in HEEP



Source of energy

Generation of hydrogen

Transport of hydrogen



Flowsheet of nuclear hydrogen genration
Consumables for NPP (fuel etc.)
NPP Construction, O&M and De-commissioning
Consumables for H2 Gen Plant (Chemicals etc.)
H2 Gen Plant Construction, O&M and De-commissioning
Consumables for H2 Transport
H2 Transport Construction, O&M and De-commissioning
EXPENDITURE
REVENUE
Energy
Hydrogen
other useful energy by-products
Electricity
Other useful by-products from H2 Gen Plant
Hydogen sale
Click respective buttons to Add or View or Edit details
Technical details of Nuclear Power Plant
Time Schedule for Nuclear Power Plant
Cost details of Nuclear Power Plant
Technical details of H2 Generation & Storage Plant
Time Schedule for H2 Generation & Storage Plant
Cost details of H2 Generation & Storage Plant
Technical details of H2 Transportation & Distribution
Time Schedule for H2 Transportation & Distribution
Cost details of H2 Transportation & Distribution
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Characteristics of the district heating

- ***Well proven:***

  Bulgaria, China, Czech Republic, Hungary, Romania, Russia, Slovakia, Sweden, Switzerland and Ukraine

- ***Usually produced in a <u>cogeneration mode</u>***

- ***<u>Limited in applications</u>***

NUCLEAR DISTRICT HEATING

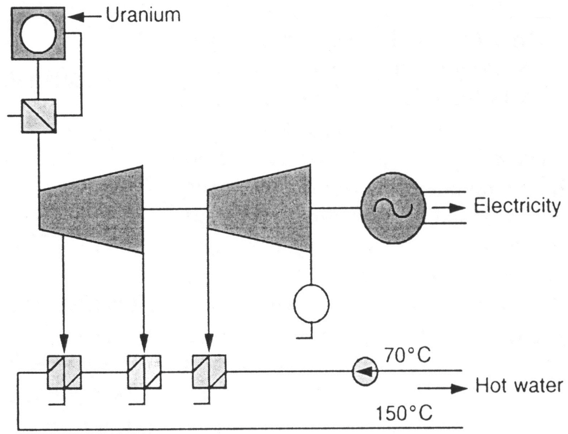
Technical features:

- *Heat distribution network*
  - Steam or hot water 80-150°C
  - Distribution up to 10-15 km
- District heat needs:
  - Typically up to 600-1200 MW_{th} for large cities
- Annual load factor < 50%
- Usually produced in a cogeneration mode

District Heating

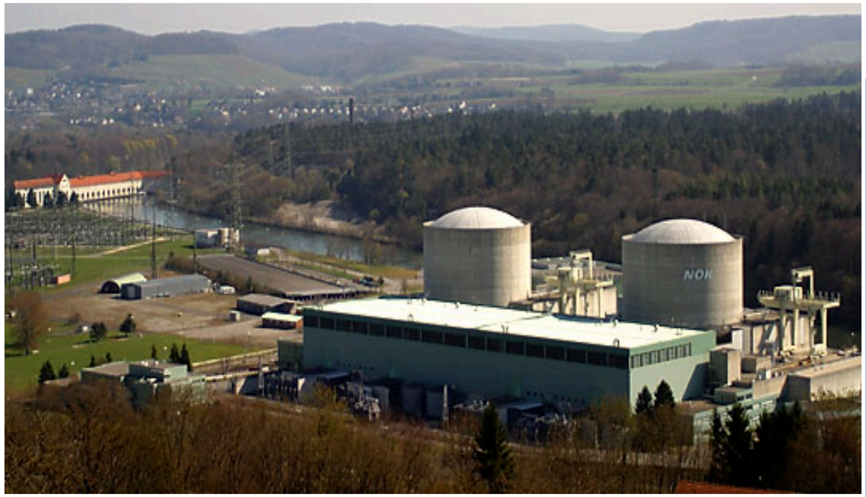
- Hot water or steam supply decentralized at 80 – 150°C temperature and at low pressures
- Developed networks in many countries with sizes of 600-1200 MW(th) for large cities and 10-50 MW(th) for smaller communities (total: ~50,000)
- Hot water systems wide spread in Germany, steam systems in the USA
- Insufficient economy for nuclear systems

Nuclear District Heating



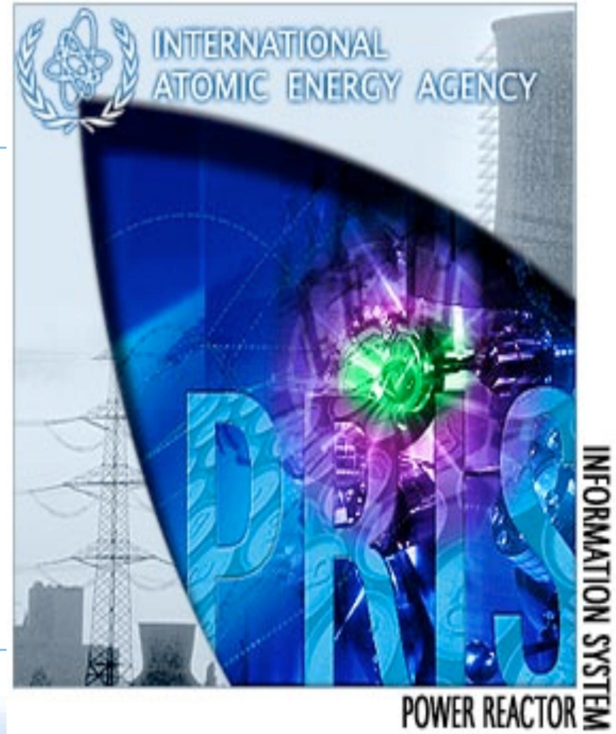
Technical feasibility demonstrated

Experience from 46 reactors in 12 countries: with two dedicated plants in Russia (Obninsk) and China (NHR-5) (IAEA 1998)



NPP Beznau, Switzerland

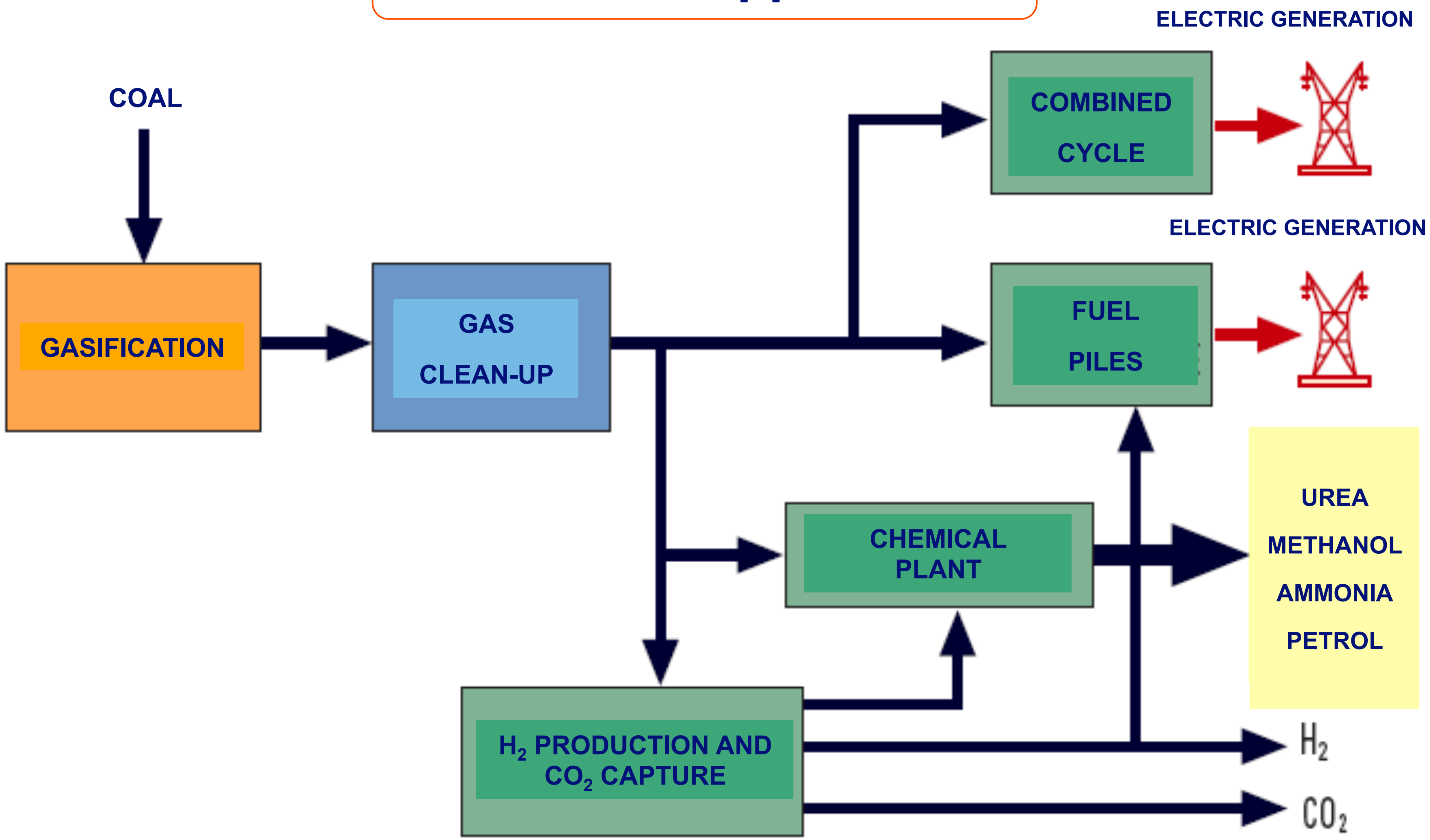
NPP Bohunice, Czech Rep., with a 40 km grid to provide hot water at 300 kg/s at 150°C



Coal Gasification

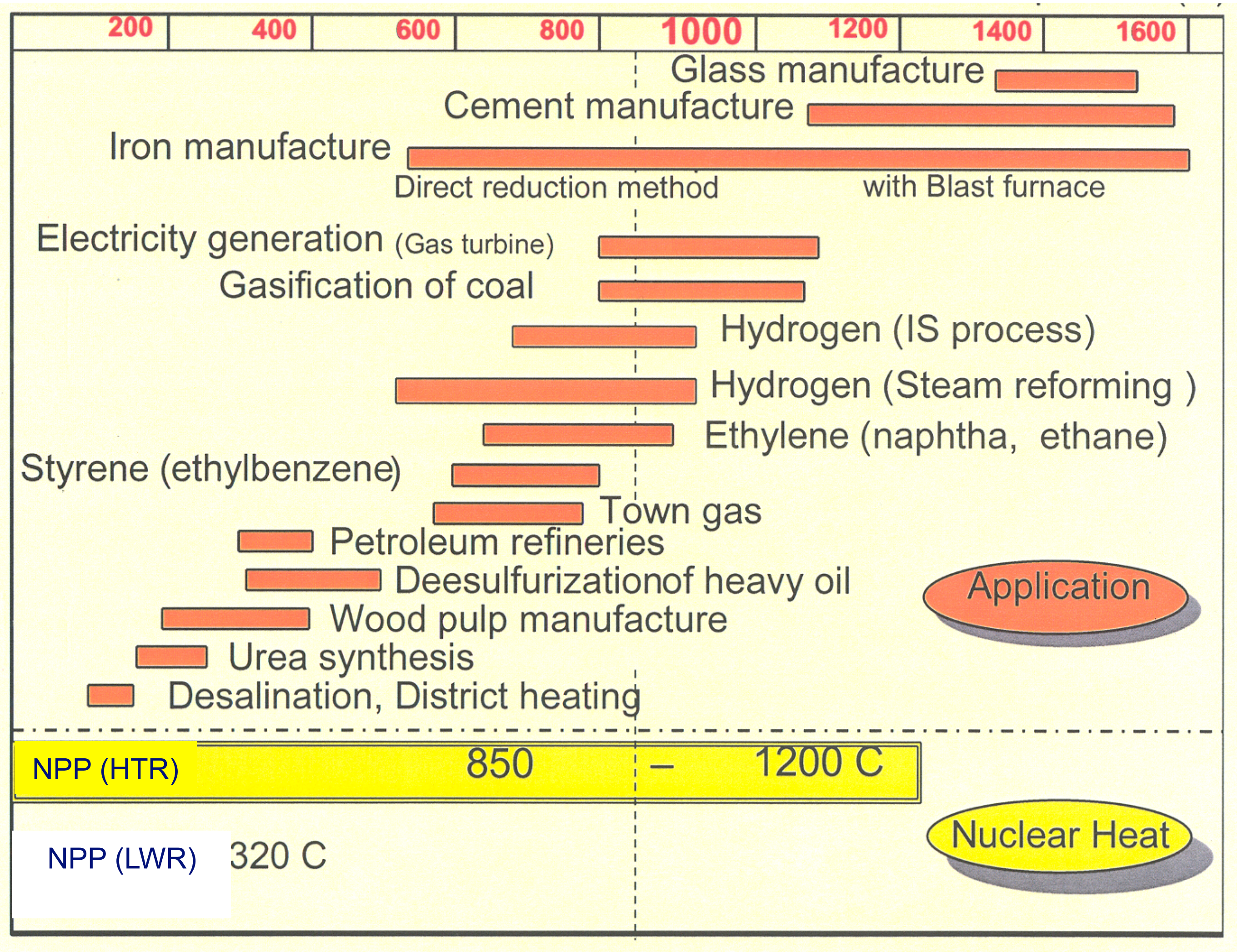
Coal Gasification

Gasification applications



Coal Gasification

Industrial Process Temperature required



Coal Liquefactions

Coal Liquefaction

- Coal liquefaction is a process that converts COAL from a solid state into liquid fuels, usually to provide substitutes for petroleum products.
- Large scale applications have existed in only a few countries, eg, Germany during WWII and South Africa since the 1960s.

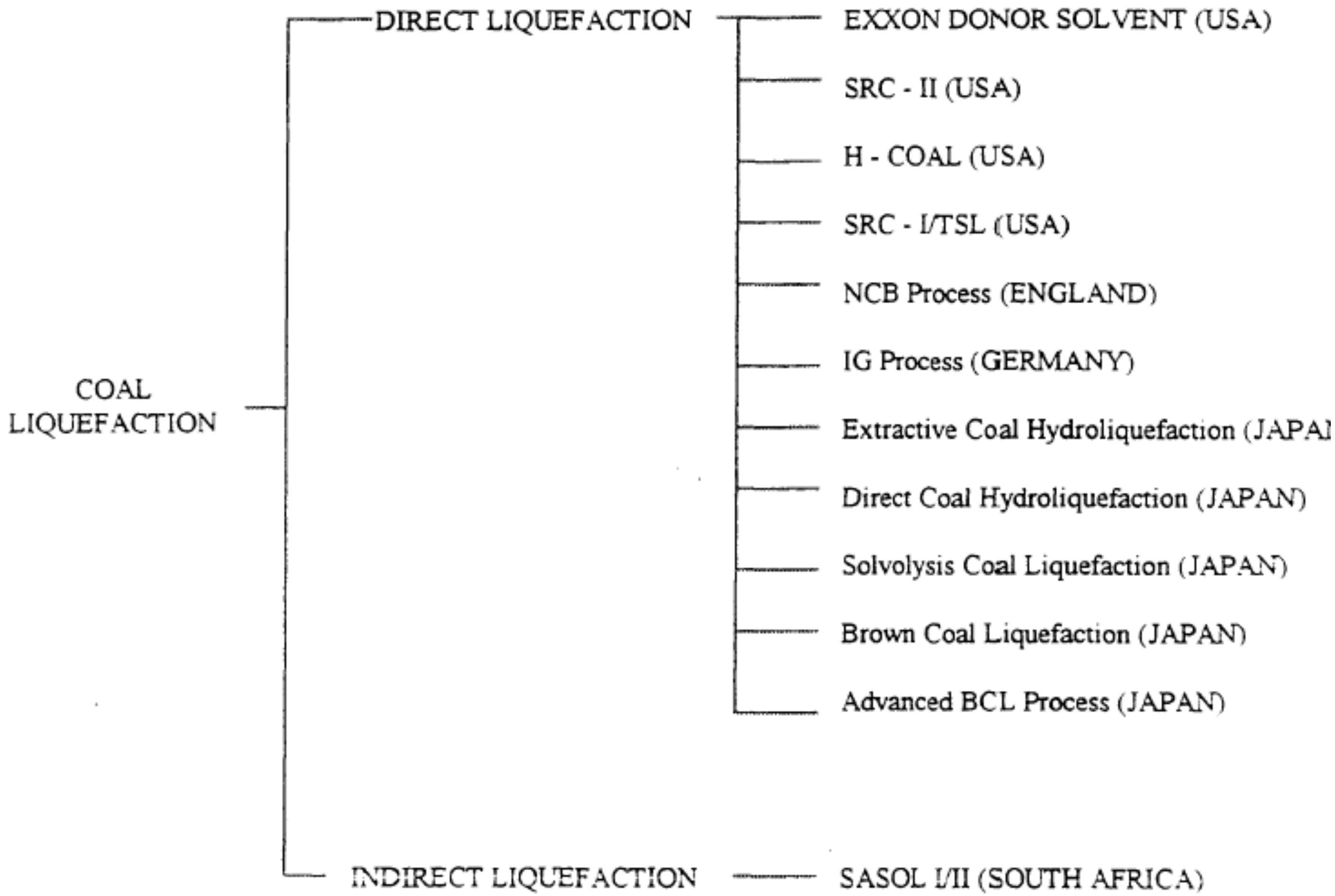
➢ There are several I&D and projects under development using direct coal liquefaction. Efficiencies of different processes are listed below:

Original Conceptual Design	57.3%
Advanced BCL Vic. Coal with Hydrotreator	60.4%
Advanced BCL Vic. Coal	66.9%
Advanced BCL Ind. Coal with Hydrotreator	65.8%
Advanced BCL Ind. Coal	70.2%

EDS	Sub-Bituminous Coal	57~58.5%
SRC-II	Bituminous Coal	66~71.0%
CC-ITSL	Bituminous Coal	67.9%

Coal Liquefaction

Former Coal liquefaction projects in the world



Enhanced oil recovery

Enhanced oil recovery

3 Types of Unconventional Oil

- **Extra-heavy oil** = *viscous oil*
  Mainly located in Venezuela

- **Oil sands**
  Mainly located in Alberta (Canada)

- **Oil shales** = *rock-like material*
  Mainly located in the USA

Enhanced oil recovery

Objective of Enhanced oil recovery

- Exploitation of Heavy oil Reserves
- Recovery of nature and degradated oil fields
- Production of Clean fuels and syngas from heavy sour crude oil and refinery tars /dirty fuels)

Enhanced oil recovery

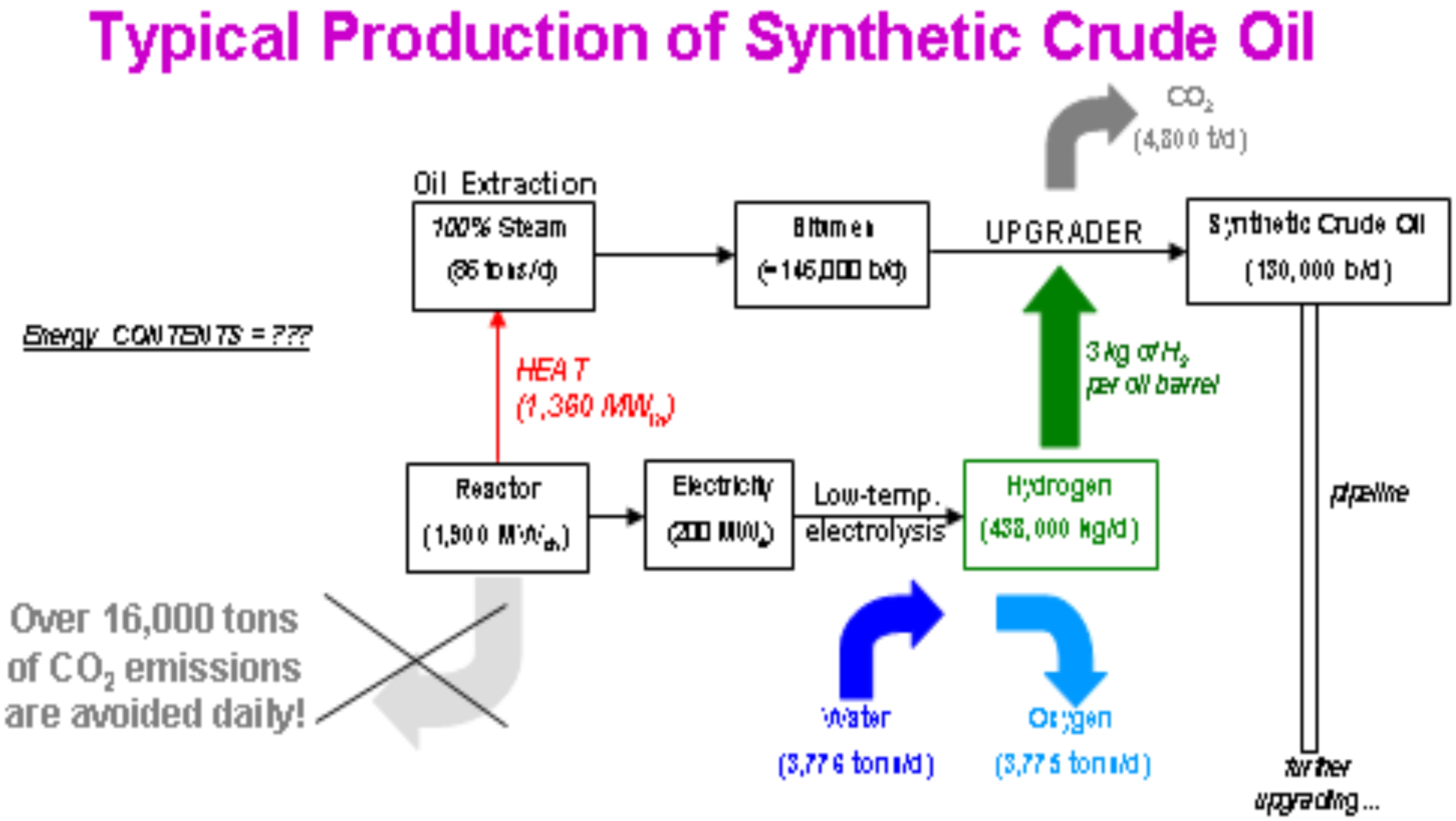
Mature and degradated oil field

- During the past 40 years, a variety of enhanced oil recovery (EOR) methods have been developed and applied to mature and mostly depleted oil reservoirs

- Each of theses methods is highly energy intensive. Electric power is used for lifting, transporting, processing, compressing and re-injecting hydrocarbons, water an injectants in and around the EOR fields
  - CO2 EOR
  - Enhanced Coalbed Methane Recovery
  - Thermal EOR: Cyclic steam and hot water injection
  - Other gas EOR: Hydrocarbon and Hydrogen injection
  - Chemical / Microbial EOR: Polymers, surfactants and alkaline chemicals

Enhanced oil recovery

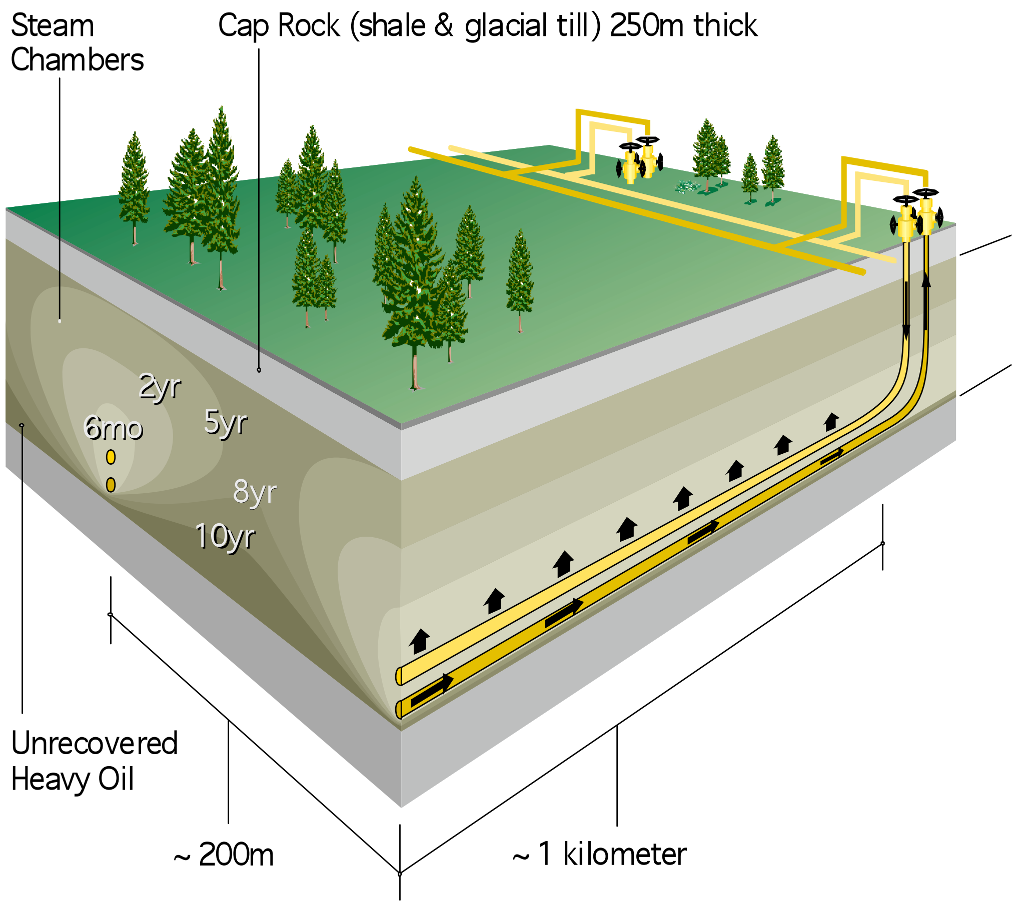
Nuclear Heavy oil Plant



STEAM FOR INDUSTRIAL APPLICATIONS
EXAMPLE: Mining Alberta's Oil Sands

- Steam assisted gravity drainage is applied for extraction of bitumen
  - Current: 1.1 Mbbl / day of bitumen
  - 2010: 2 Mbbl / day
  - 2030: 5 Mbbl / day

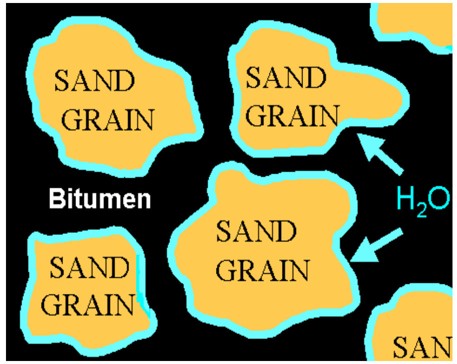
  (Ref: Alberta Chamber of Resources)
- Requires steam at 2-6 MPa
- Currently use natural gas representing 18 % of the energy content of the mined bitumen
- An ACR-1000 can supply steam for 0.35 Mbbl / day



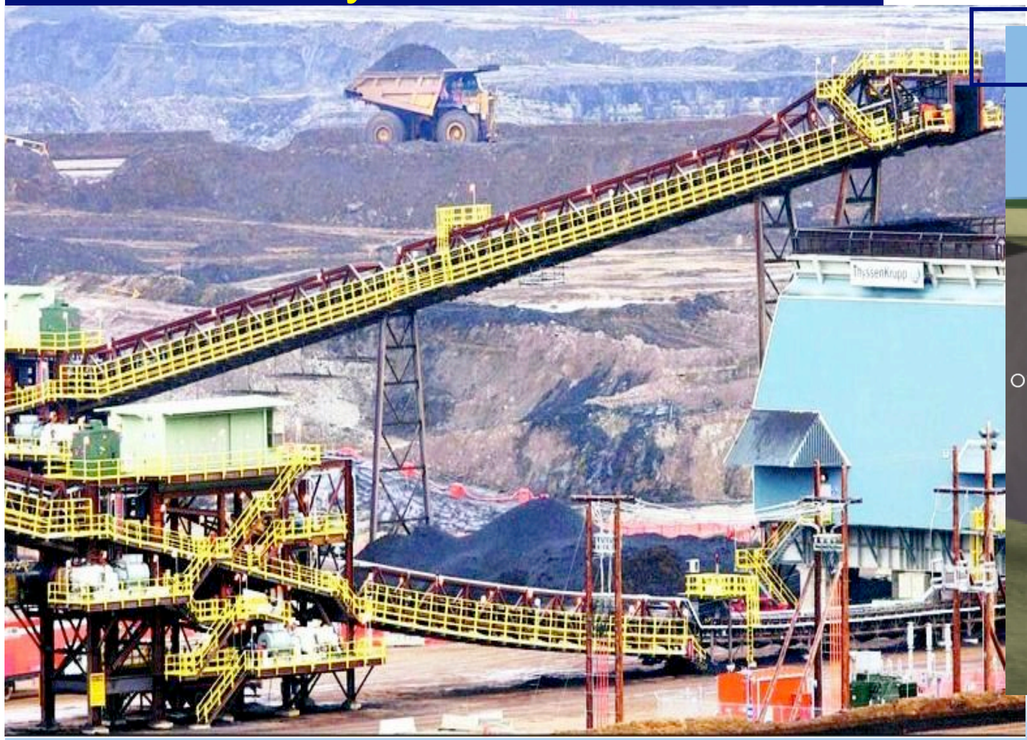
Tertiary Oil Recovery

Flooding with steam

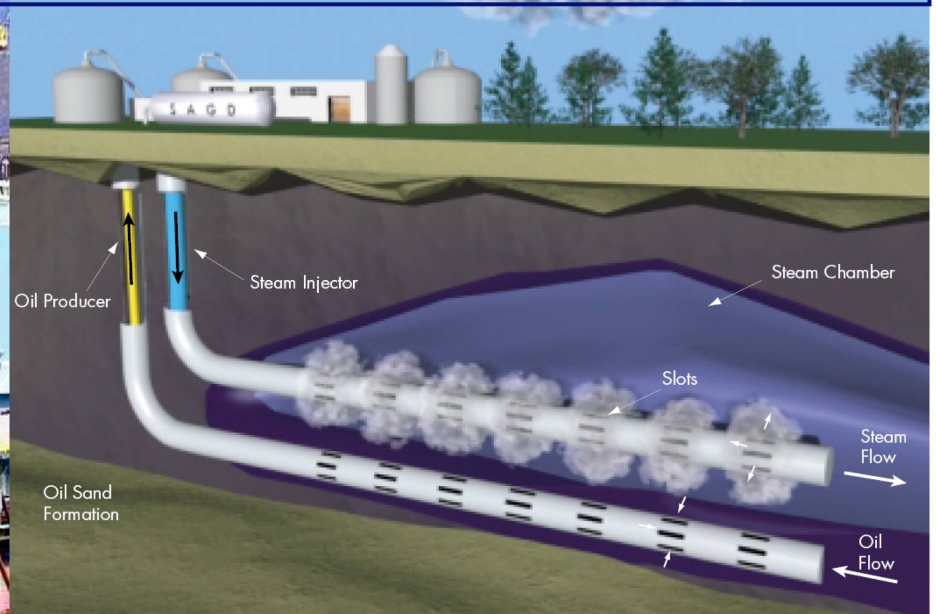
@ 200-340°C, 10-15 MPa



Fort McMurray, Canada

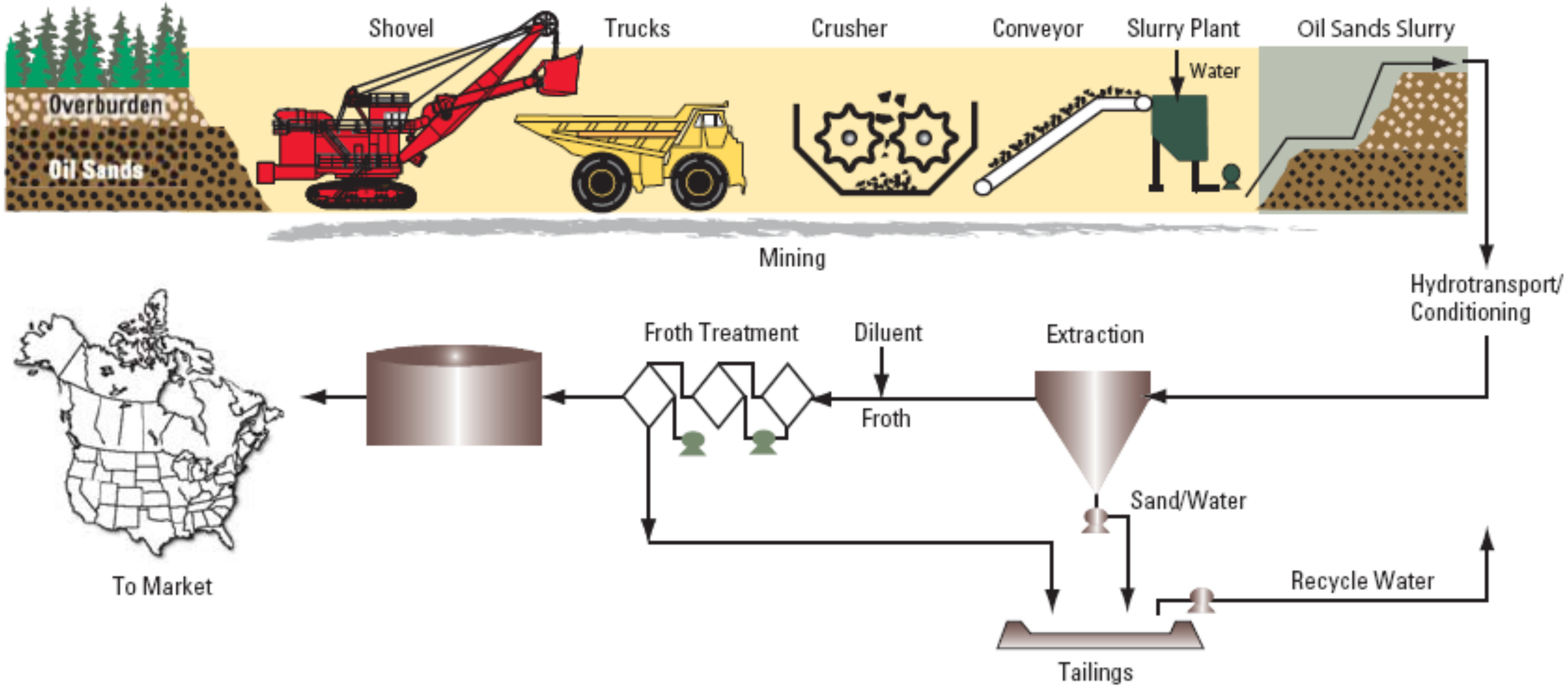


Steam-Assisted Gravity Drainage



one well for steam injection,
the other for production

CANDU-6 Cogeneration for Bitumen Extraction using Open Pit Mining



Summary

- Non-electrical applications have now 700 reactor years of experience
- Nuclear desalination can be a viable option
- Hydrogen production is an important non-electrical application
- No recent increase in district heating and process heat applications

Summary

- **Short term** prospects: Current Water cooled reactors needs to be considered for desalination, hydrogen production, and other appli.

- **Near term** prospects: HTR + WCR

CONCLUSIONS

Nuclear energy can:

- Penetrate energy sectors **now served** by fossil fuels as:
  - **seawater desalination**
  - **district heating**
  - **heat for industrial processes**
- Provide ***near-term***, greenhouse gas free, energy for transportation

Prospects:

- **Short and near Near-term appl are seen through cogeneration (especially for desalination) with Water Reactors,**
- **Mid-term and long term appl with HTR**

Opportunity to participate in the development of low carbon foot print desalination system

- ***NEW CRP*** on: **New Technologies for seawater Desalination using nuclear energy (2009-2011)**
  - **The 1st RCM on above is 27-28 Oct.**

  (All invited to participate)

- **Support the *Concept Design* of a more energy-efficient desalination system.**

The design is based on heat pipe technology (IP protected).

…Thank you for your attention

International Atomic Energy Agency