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Non-electric Applications of Nuclear Power: An Overview

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Non-electric Applications of Nuclear Power: An Overview

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Contents

- Prospects of Non-electric Applications NEA
- Status of NEA
- Summary and conclusion

World energy use

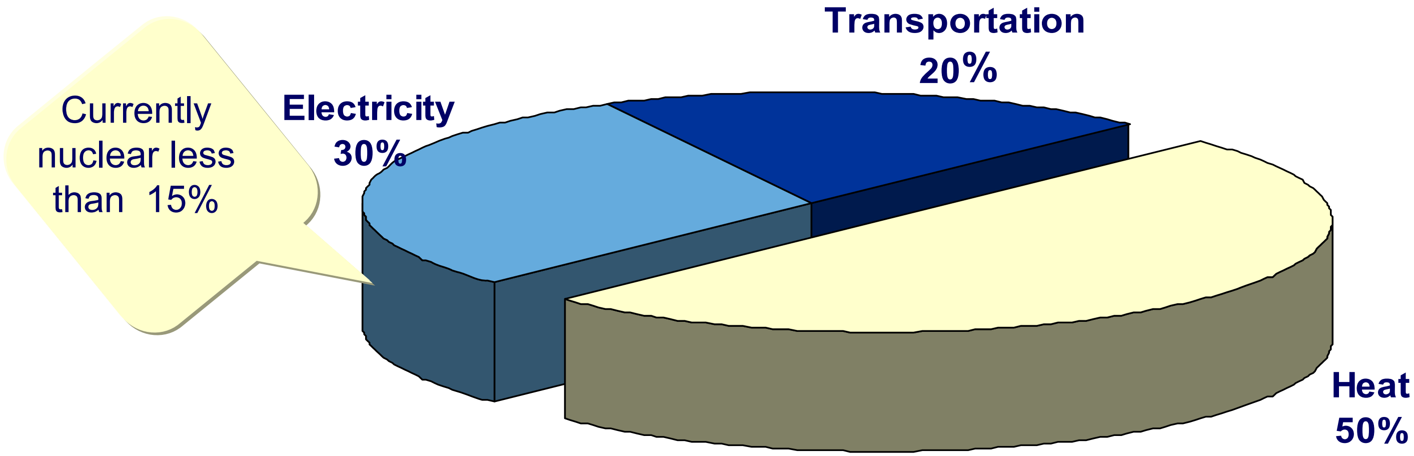
Fuel	*Percentage (%)*	*Present trends*
Oil	**39**	**Short-term: Building of additional plants continues**
Coal	**25**	**Building of additional plants continues**
Gas	**22**	**Short-term – Building of additional plants continues; gas turbine combined cycle plants considered the cheapest of fossil fuelled 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.**

Non-electric Applications of nuclear energy

- 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.

Less than 1% of the heat generated in nuclear reactors is used for non-electric applications

Energy consumption by application

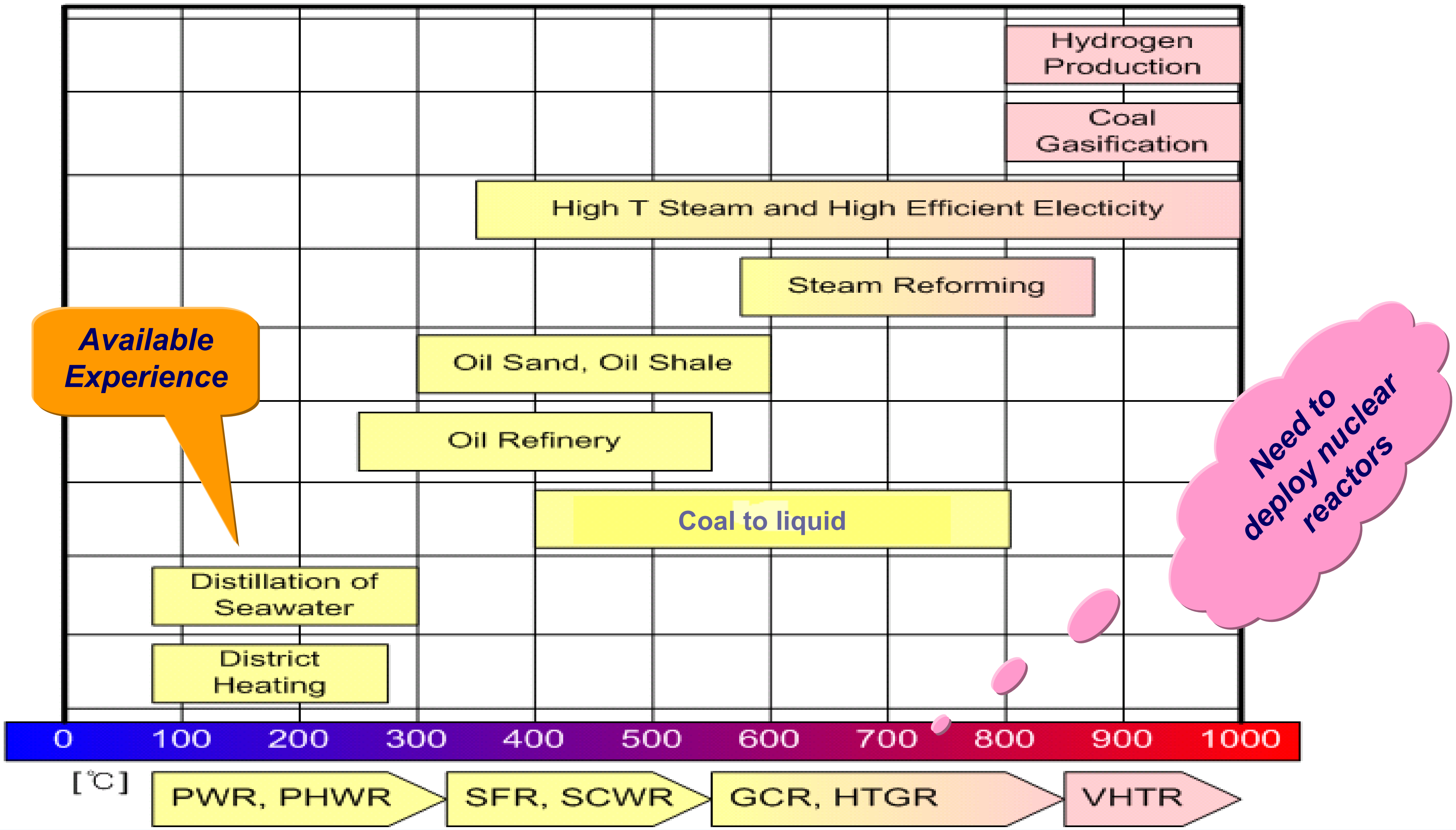


Nuclear could make bigger impact by penetrating heat and transportation sectors

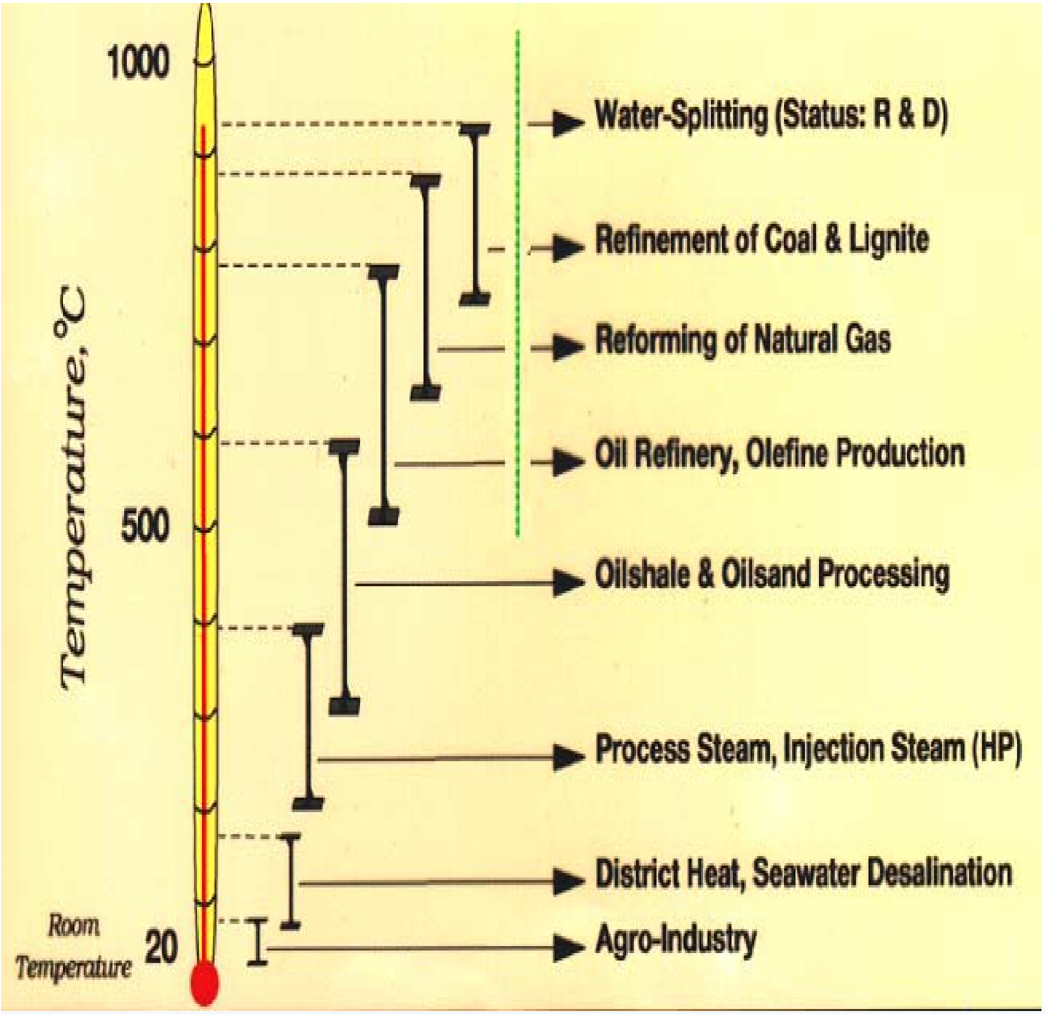
Industrial process vs. temperature

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



NUCLEAR PLANTS CAN PROVIDE THE HEAT REQUIRED FOR NON ELECTRIC APPLICATIONS

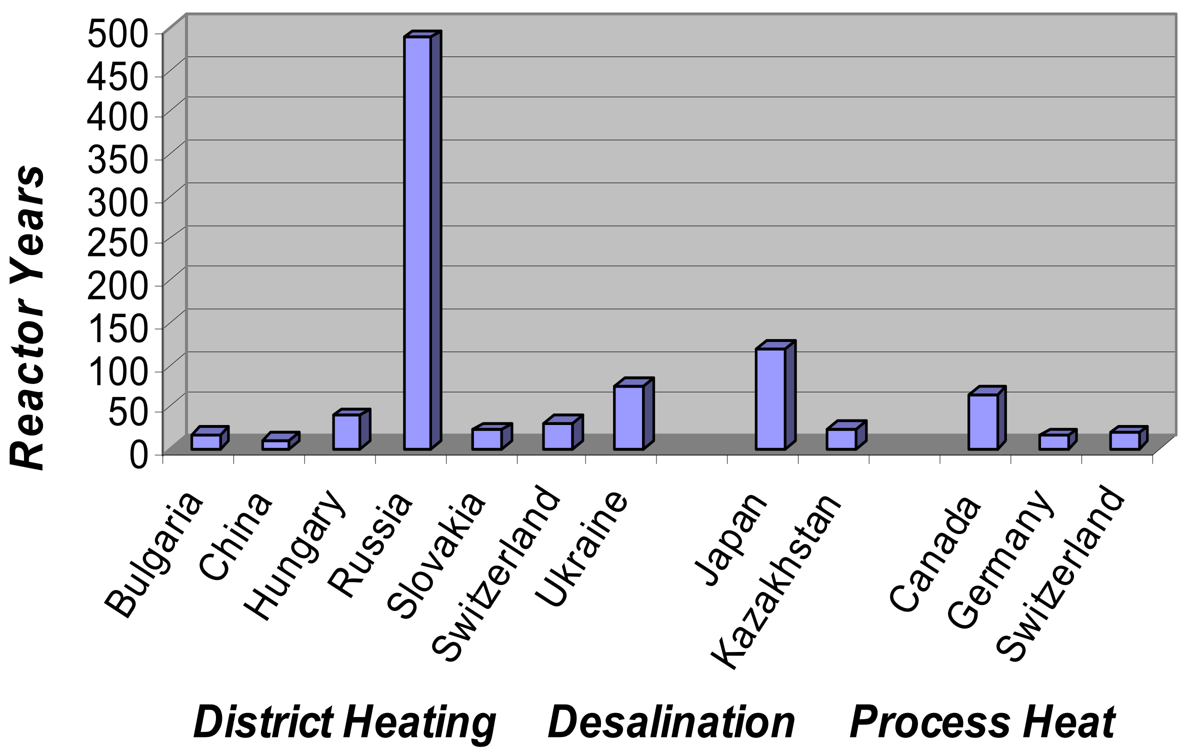


Reactor Type	Primary Coolant Inlet & Outlet Temperatures (oC)
Pressurized Water Reactor (PWR)	280-320
Water Reactor (BWR)	280-290
Heavy Water Reactor (HWR)	250- 300
Liquid Metal-cooled Reactor (LMCR)	390-540
High Temperature Gas-cooled Reactor (HTGR)	500-1000

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

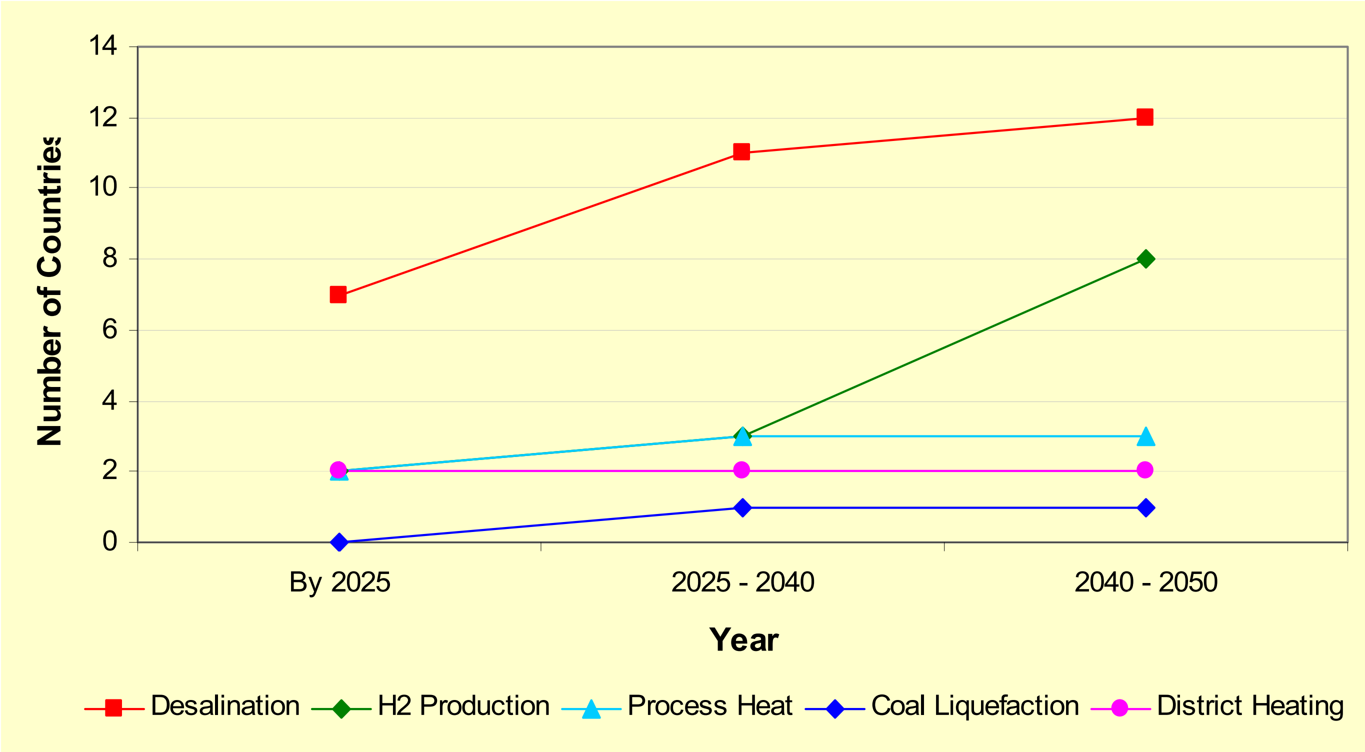
Operating experience in heat applications



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

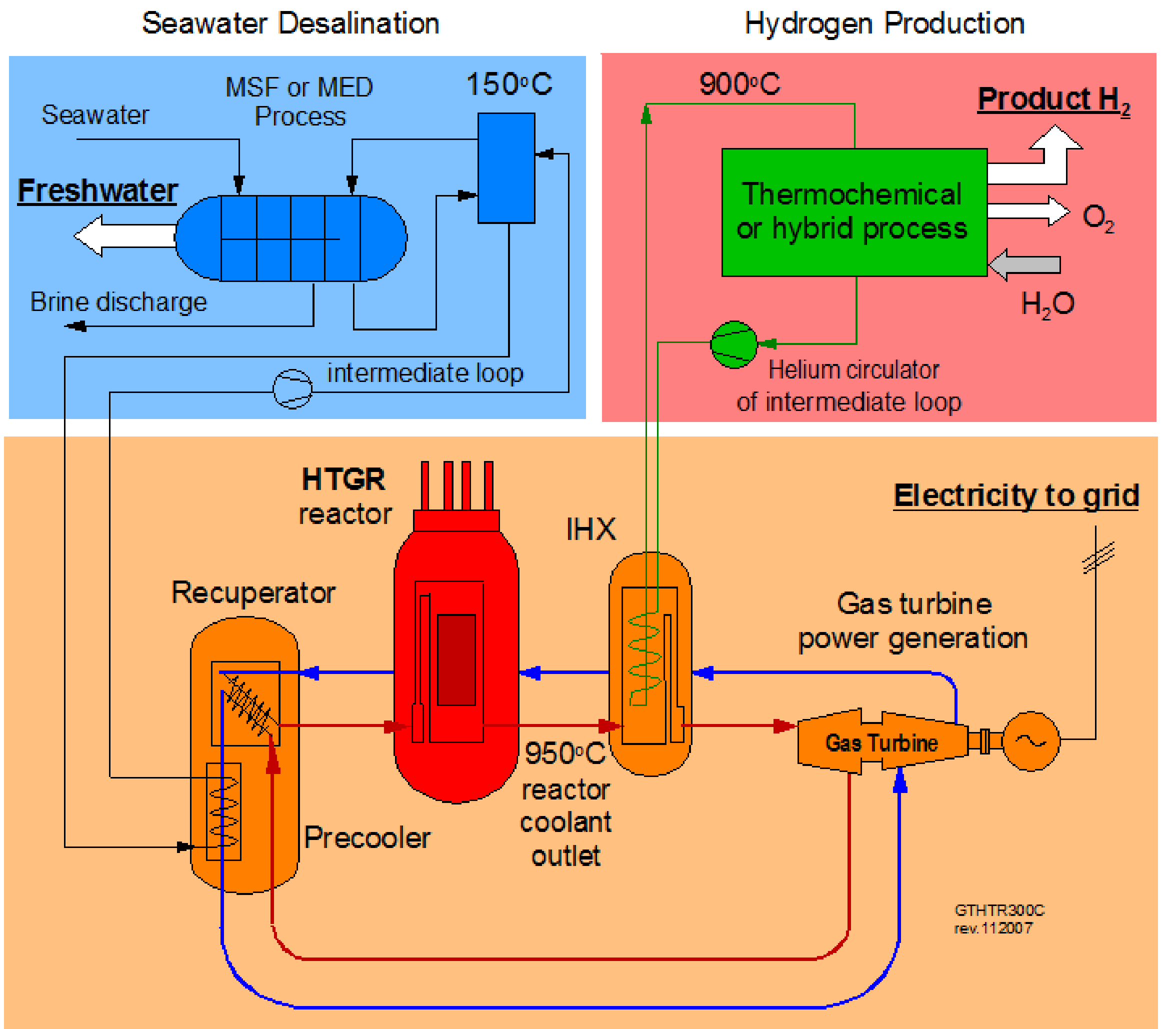


By 2050, desalination and hydrogen production are most preferred cogeneration of NPPs.

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

Preferred option: Cogeneration



Major non electric applications

- **Nuclear desalination: Proven/ required for sustainability**
- **Hydrogen Production: strong socio-economic demand**
- **District heating: well proven/ Good example of cogeneration concept**
- **Industrial process heat applications: 99% of the industrial users need a thermal power less than 300 MW i.e. SMRs**

Hydrogen production

Hydrogen Demand

World H_2 production per year ≅ 500 billion Nm^3

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

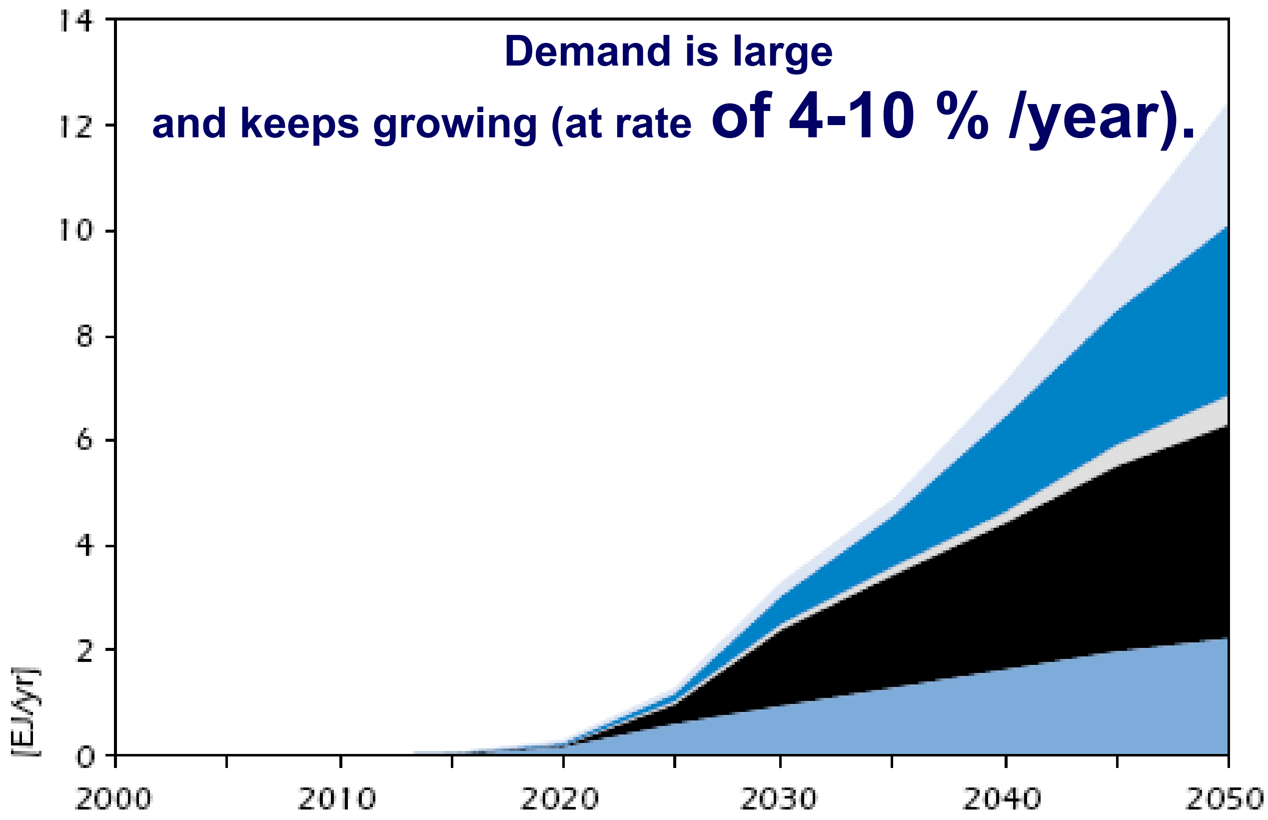
Raw material used ⇒

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

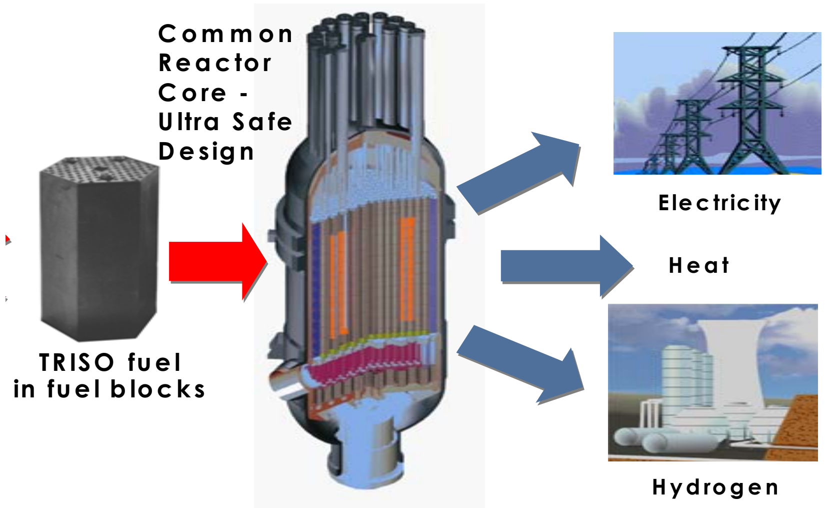


Increased interest in carbon-free hydrogen

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

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.**



Currently: Reforming of hard coal and oil (gasification) is 96% of the annual hydrogen production

Characteristics of nuclear 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

- **Technical**
  - Reactor designs & materials.
  - Need for Chemical processes operate efficiently and reliably.
  - Large-scale production & storage of hydrogen.
  - Overcome barriers to economic hydrogen generation.

- **Non technical**

  Public Opinion
  Nuclear accident liability
  Licensing/regulatory requirement
  Need for Large and Long-term investment
  Safety of Coupling between Nuclear plant and Chemical plant

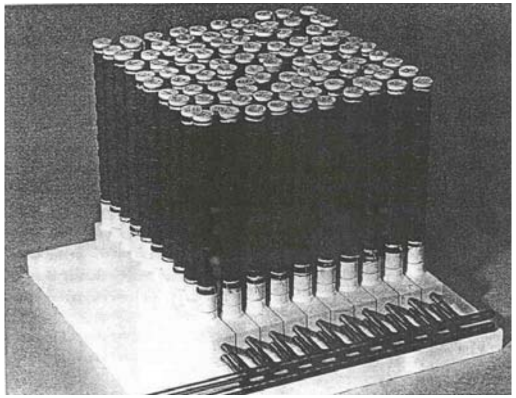
Nuclear Hydrogen Production

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

- **Decomposition of Water:**
  - **Thermo-chemical Water Splitting (above 900 C).**
  - **Electrolysis:**
    - **Low-temperature (~ 100 C).**
    - **High-temperature (above 800 C):** a reverse reaction of the Solid-oxide Fuel Cell

Nuclear Hydrogen production

High temperature ⇨ High efficiency

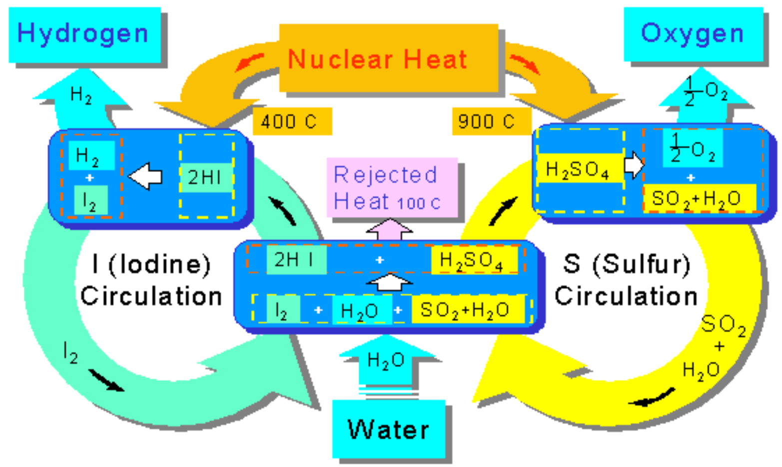


- High Temperature Electrolysis (~ 900 C).

Advances in HTR ➡ *Increased interest in Hydrogen economy*

- 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 (THE) using nuclear electricity and heat

Compared to thermochemical cycles, HTE:

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

- **Advantage: Build on existing fuel cell technology .**

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

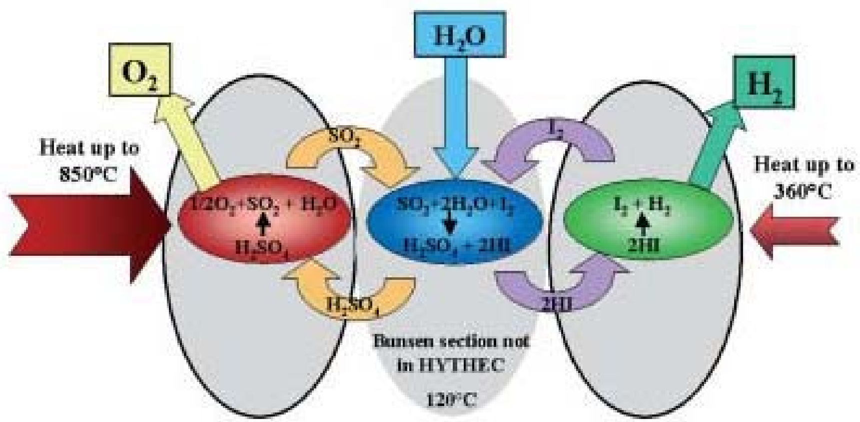
200 m^3/h

Electrolysis is promising particularly in the near term future

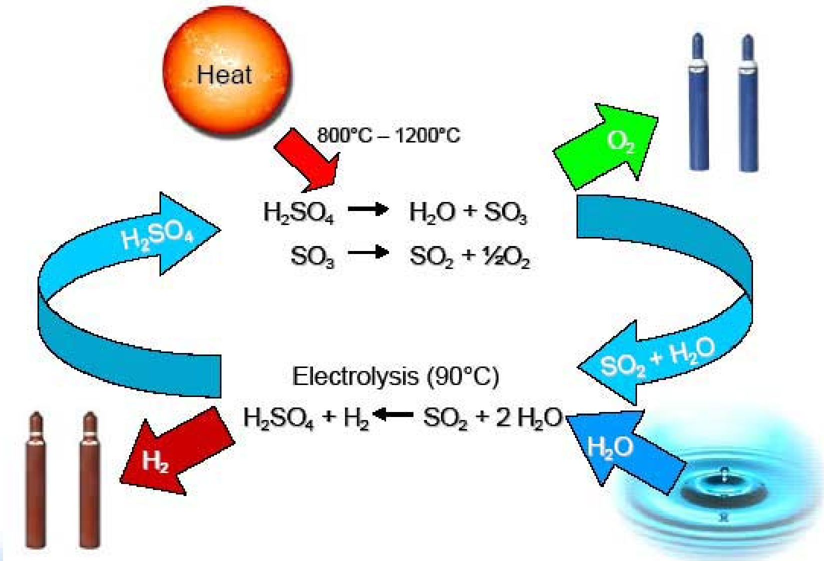
Hydrogen Production Alternatives

Hydrogen Thermochemical Cycles

- Sulphur-Iodine (S_I) cycle

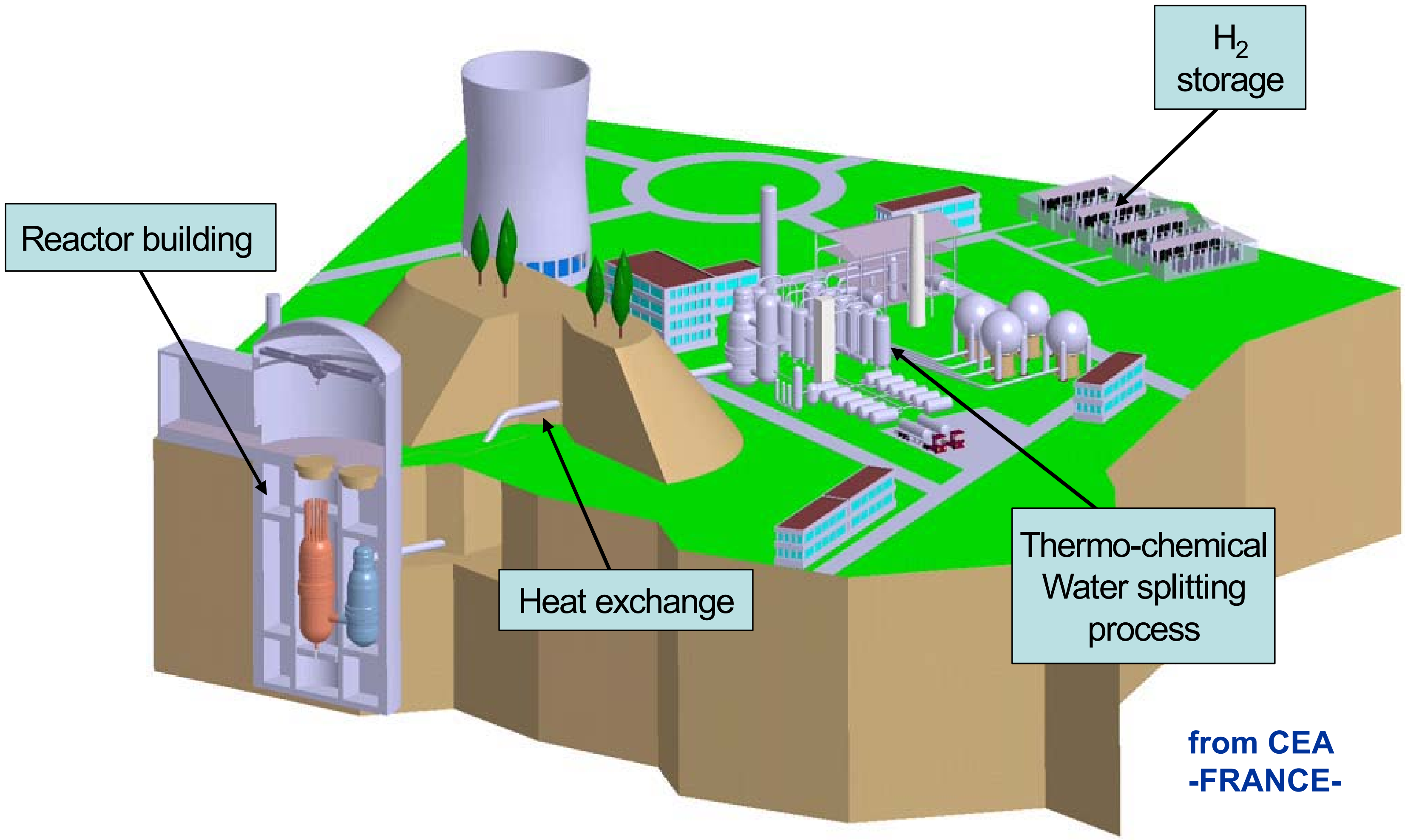


- Hybrid-Sulphur (HyS) cycle.



Nuclear Hydrogen Production

Potential Arrangement of 600 MW VHTR for H2 Production



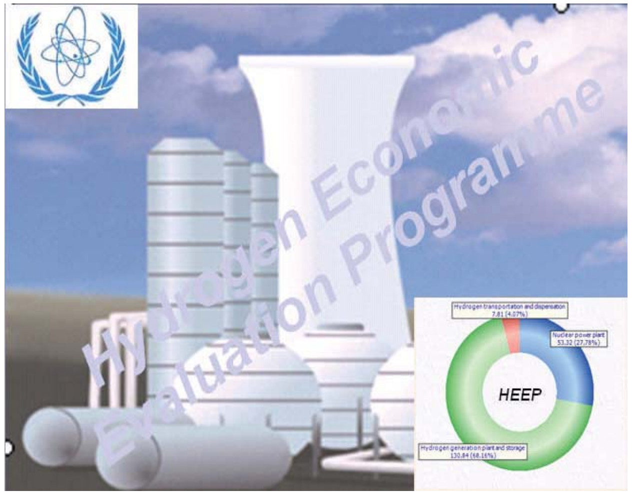
from CEA
-FRANCE-

IAEA activities on Hydrogen Production

Objective: **Support demonstration of nuclear hydrogen production**

- **Activities: CRP, Forums, publications…etc.**

- **Provide tools:**
  - **HEEP**



District Heating

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

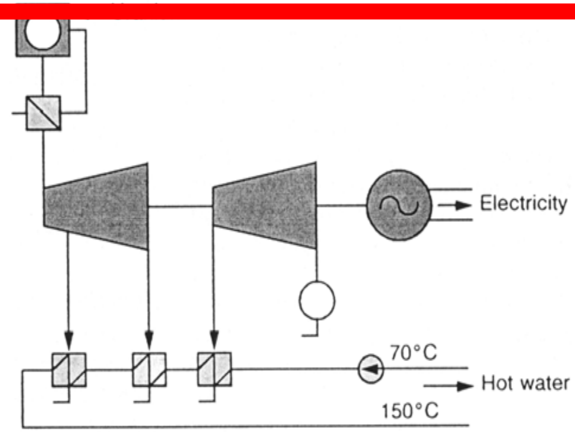
District Heating

- 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

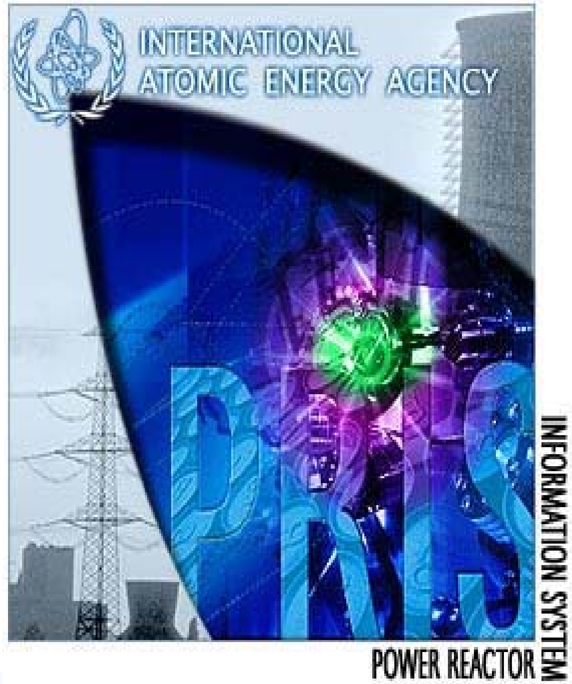
Technical feasibility demonstrated

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



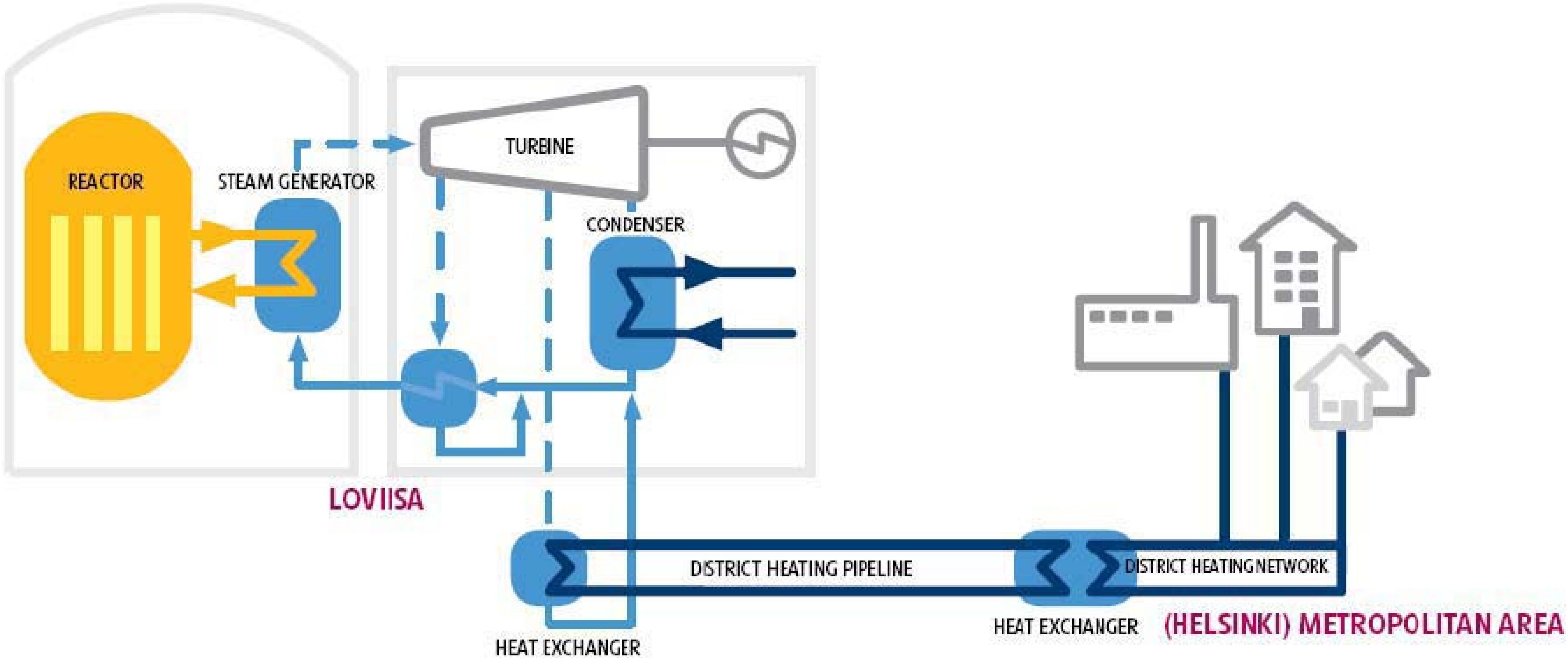
Latest news from Finland

PWR for District Heating

Heat would be transported to the Helsinki metropolitan area:

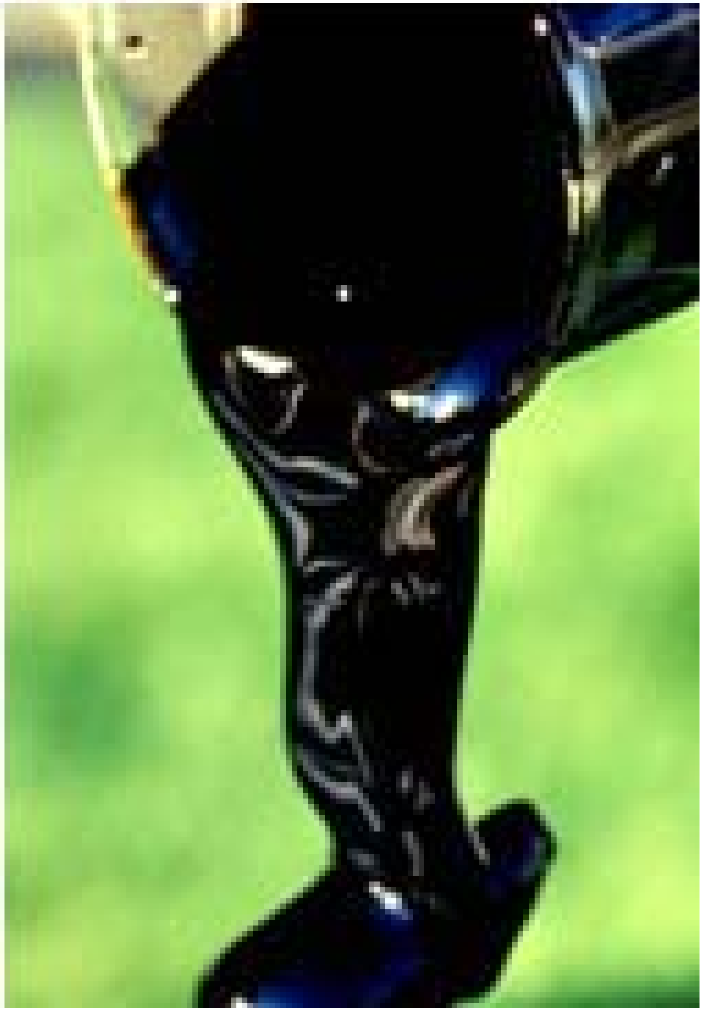
-distance from Loviisa NPP is about 80 km

-heat capacity up to 1000 MW



Source: Harri Tuomisto Fortum Power 9 March 2010

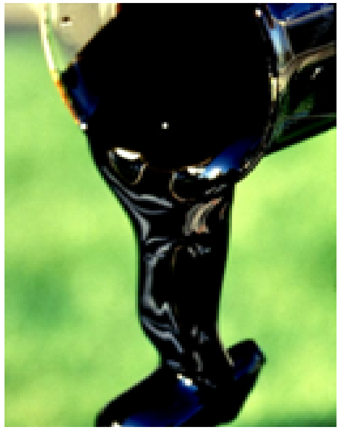
Enhanced Oil Recovery



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



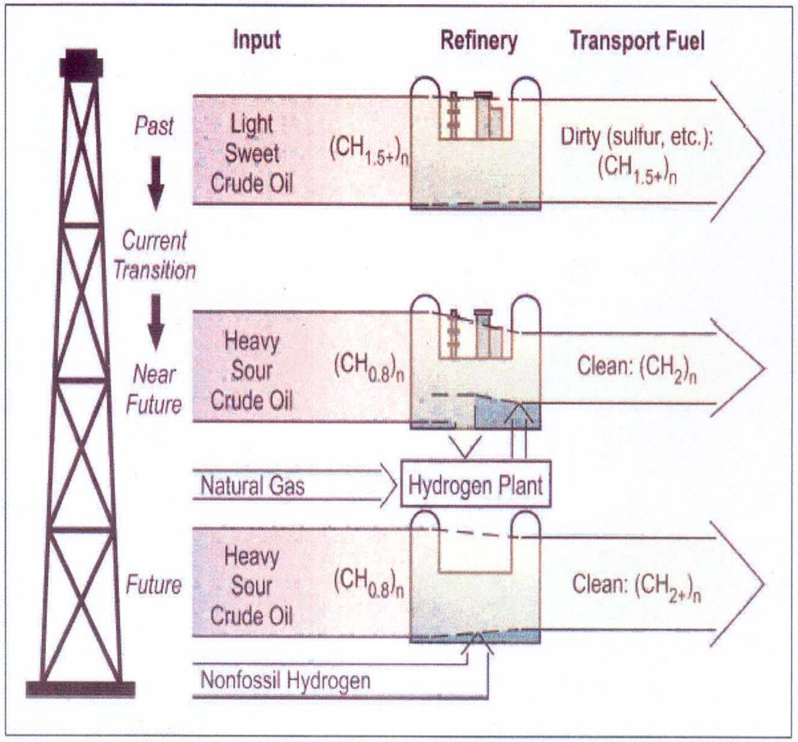
Enhanced oil recovery

Pathways for Enhanced oil recovery

- Exploitation of Heavy oils 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

Oil Quality improvement

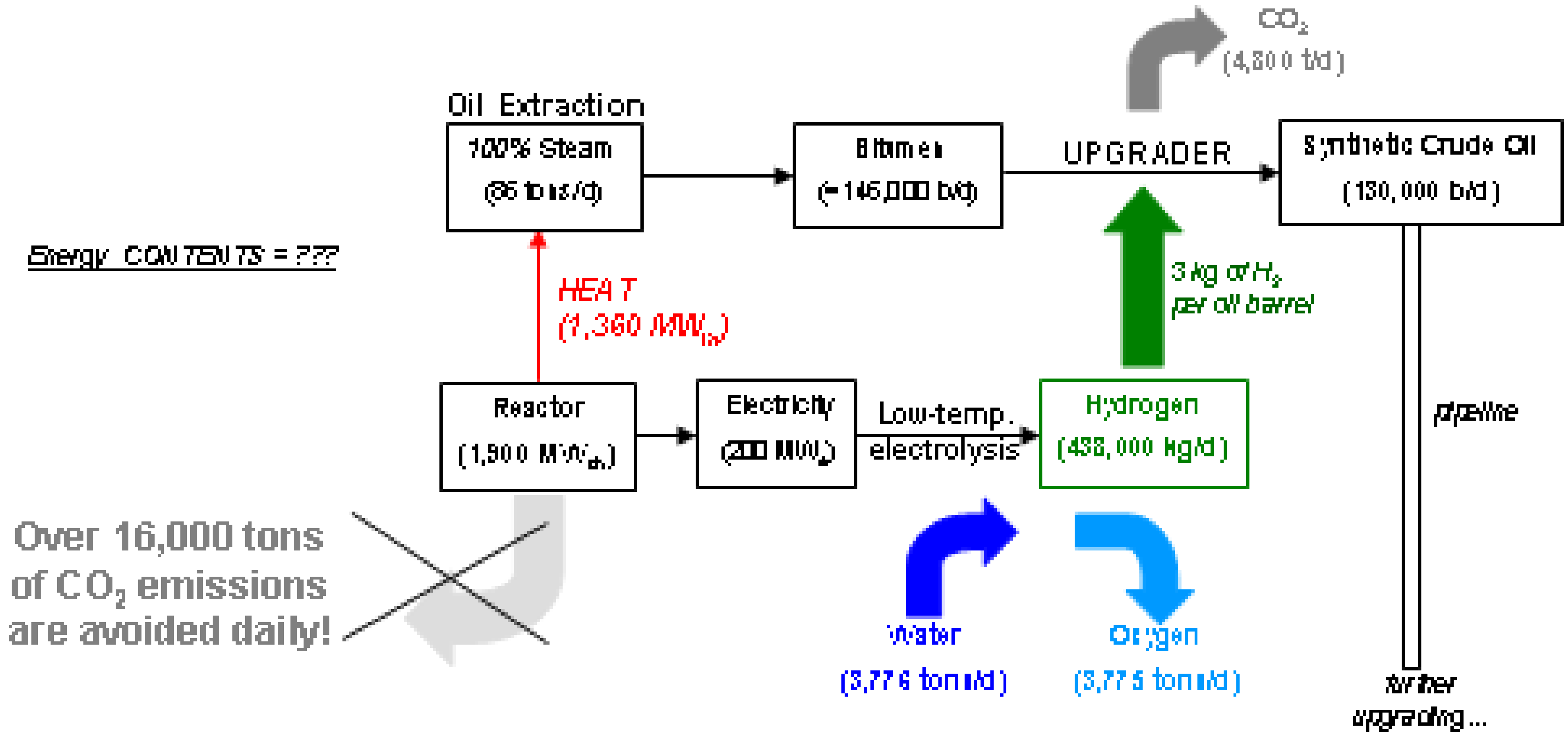


- During the past 40 years, a variety of enhanced oil recovery (EOR) methods have been used.
- Theses methods are very energy intensive.
- Electric power is used for: lifting, transporting, processing, compressing and re-injecting hydrocarbons, water
- Methods are:
  - CO2 EOR
  - Enhanced Coalbed Methane 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

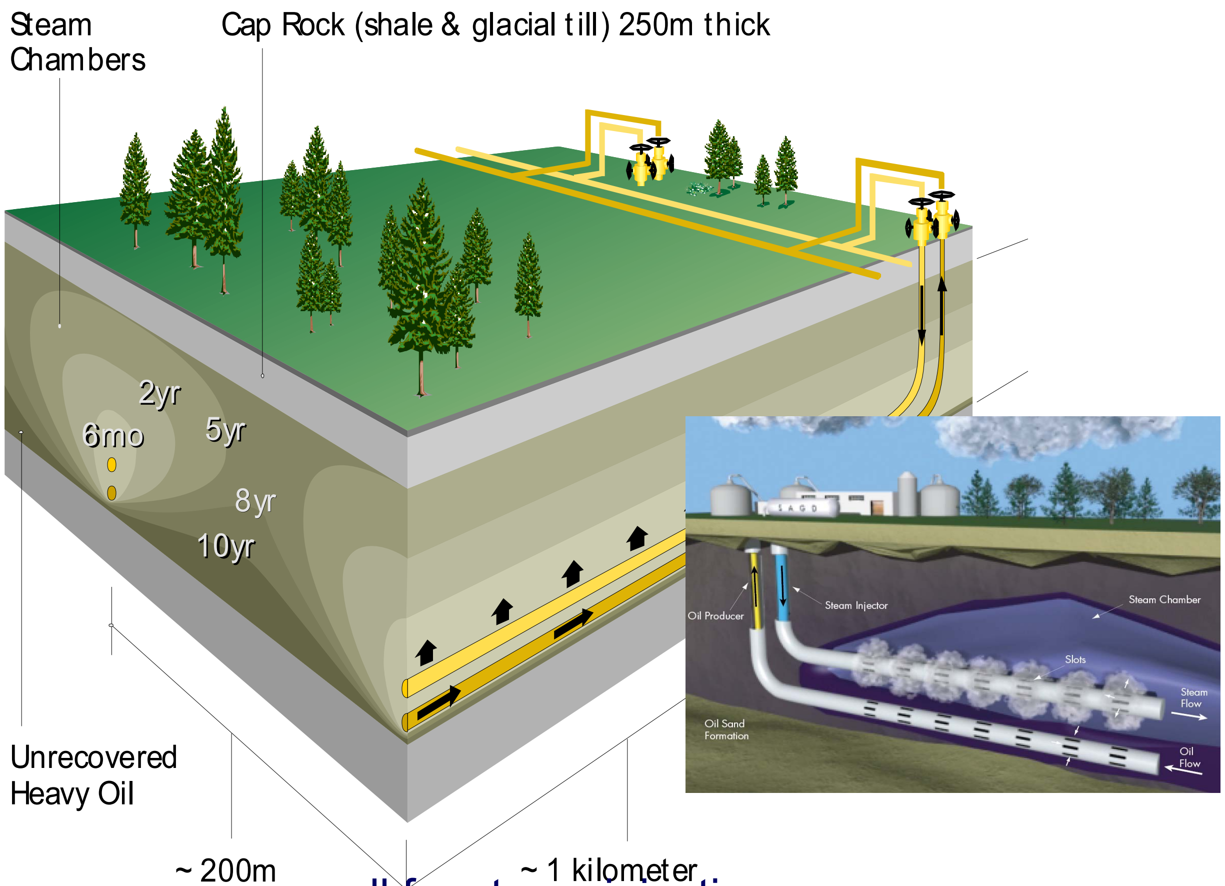
Typical Production of Synthetic Crude Oil



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



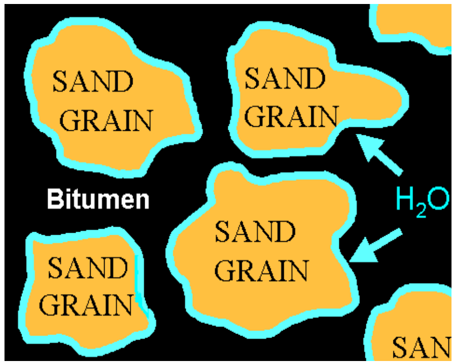
one well for steam injection, the other for production

Tertiary Oil Recovery

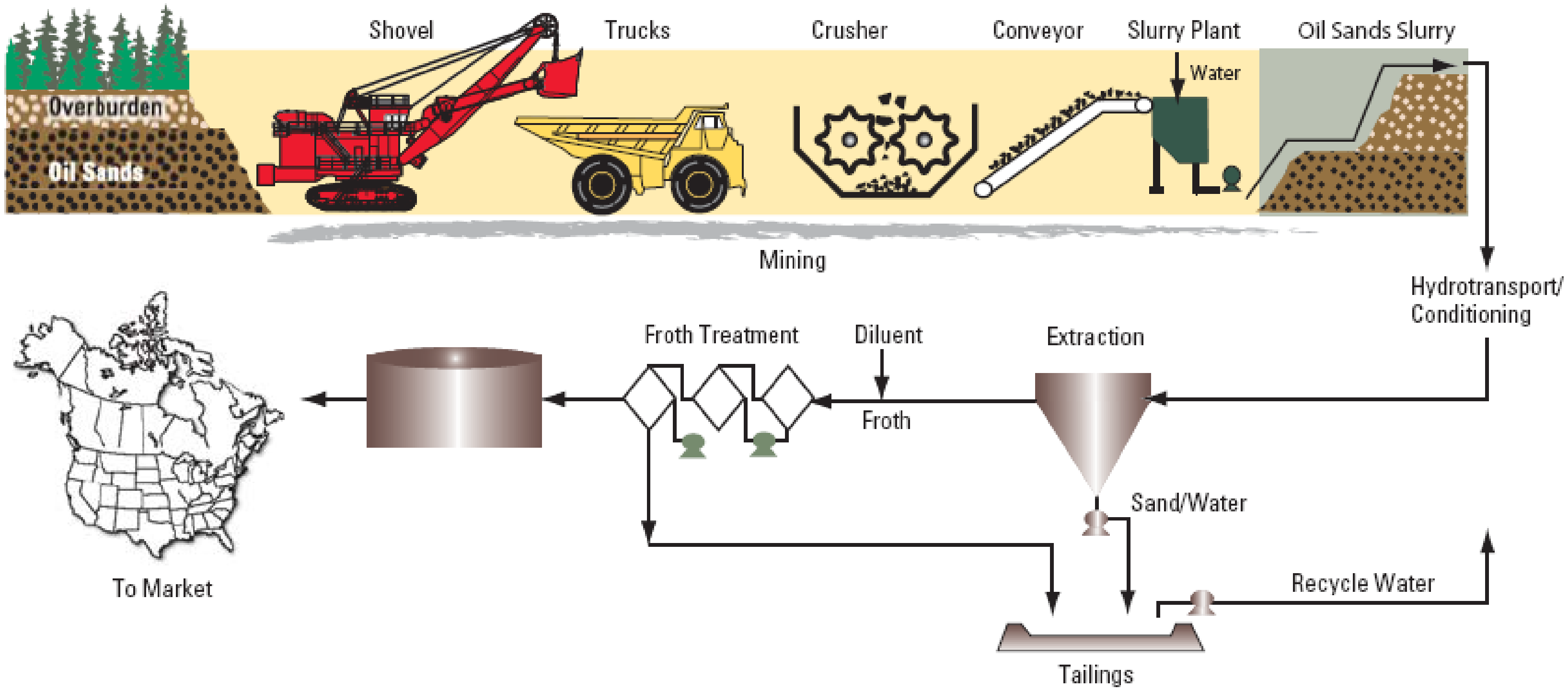
Flooding with steam

@ 200-340°C, 10-15 MPa

Fort McMurray, Canada

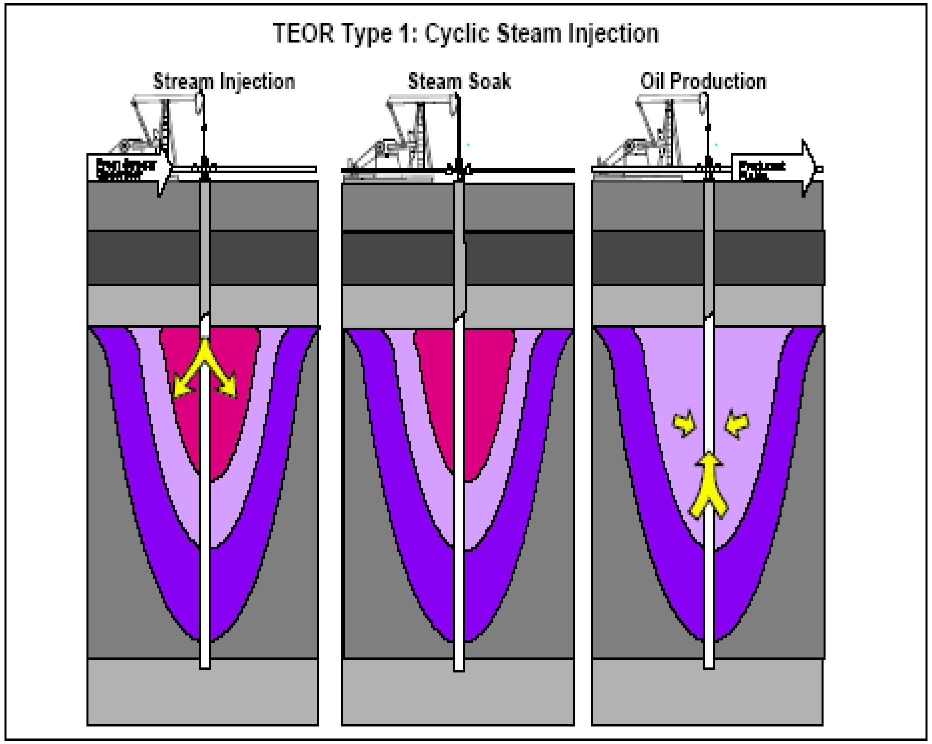


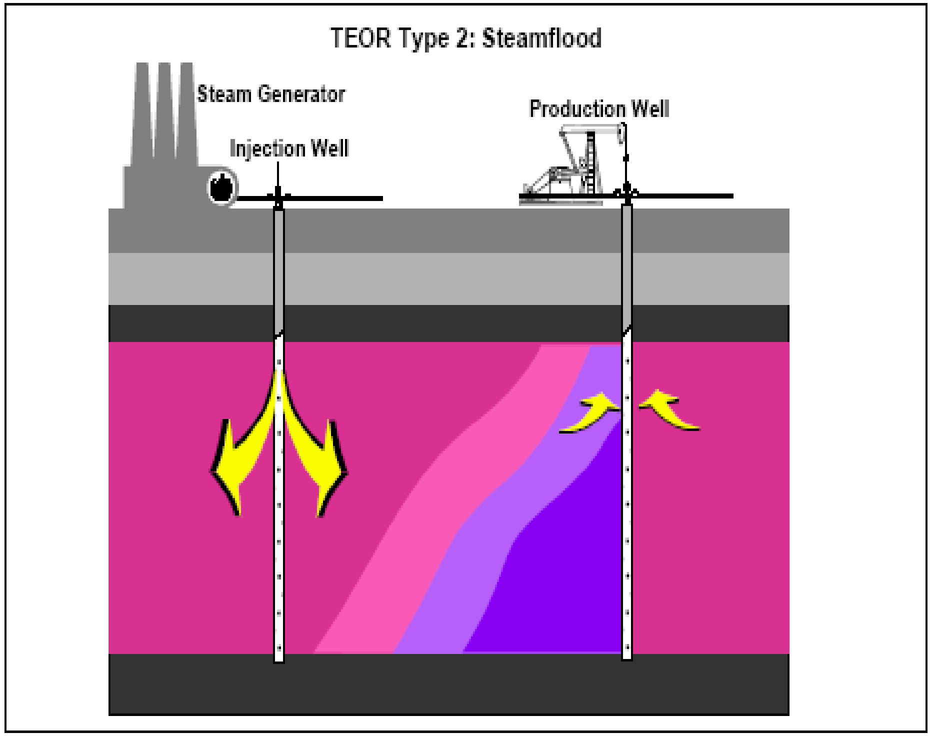
CANDU-6 Cogeneration for Bitumen Extraction using Open Pit Mining



Enhanced oil recovery

Thermal EOR: Cycle steam and hot water injection



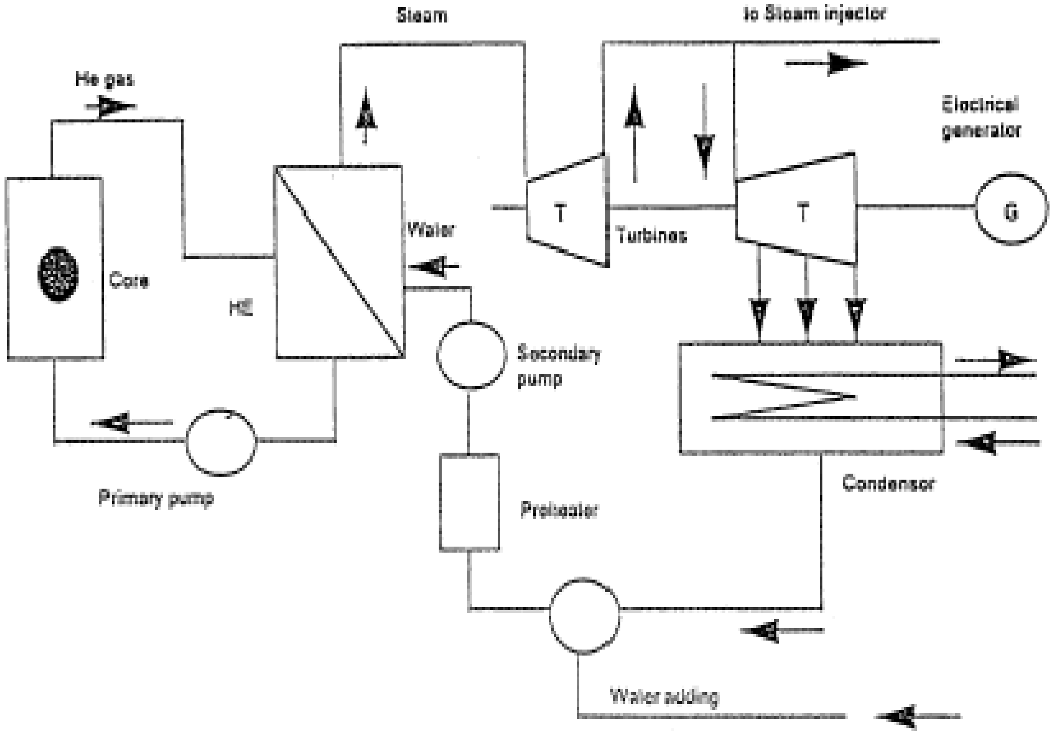


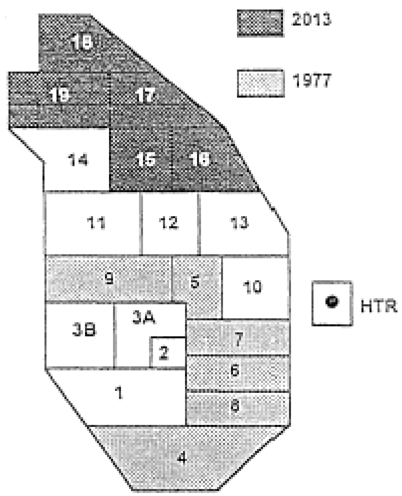
Enhanced oil recovery

Steam Flood Project (Indonesia)

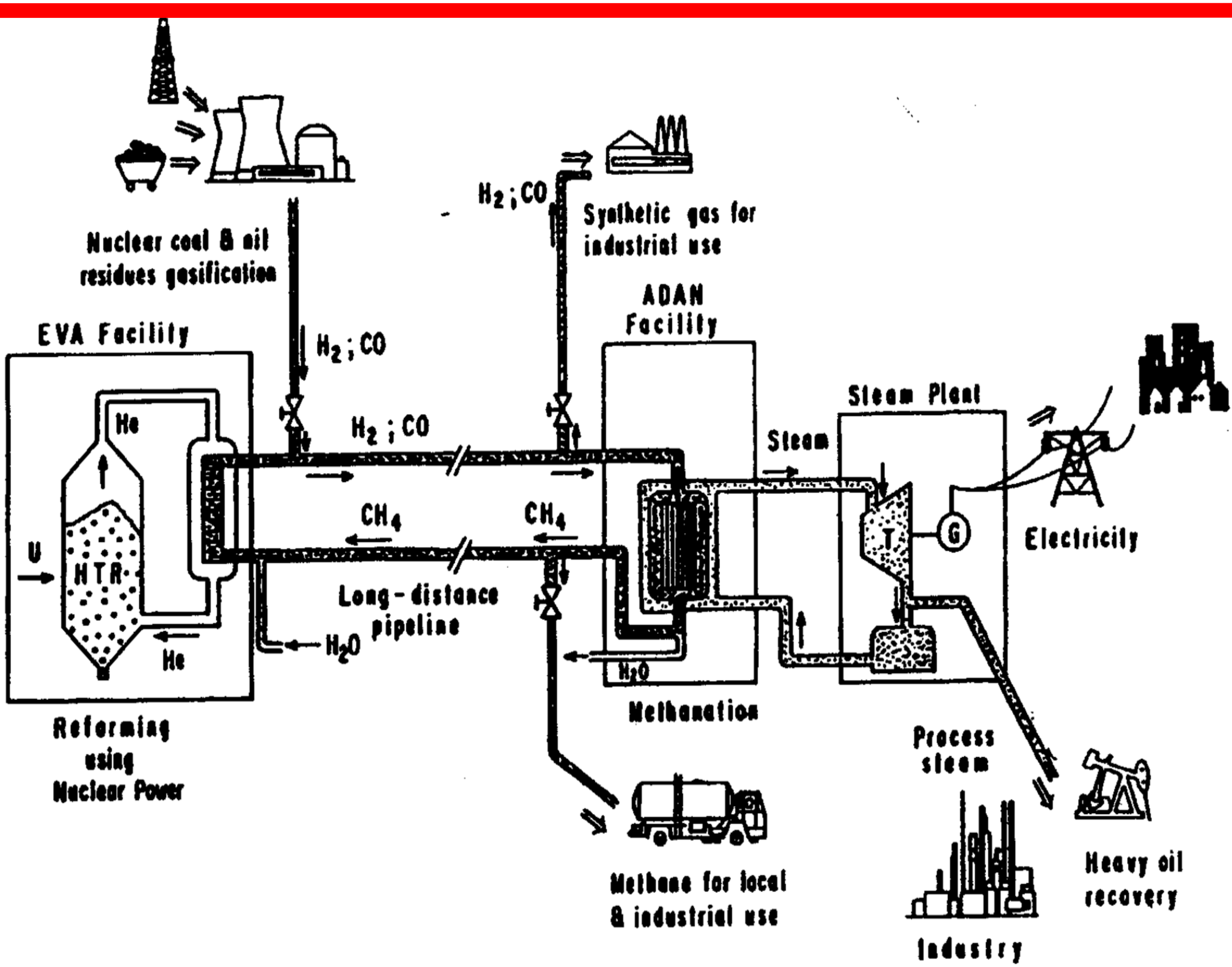
- **Duri crude: medium heavy Type (21ºAPI), viscous and high wax content (study started in 1987)**

HTR 200 MWth
Steam Pressure=150 bar
Steam Temperature= 530ºC
Electric generator produces=25-30 MW





Enhanced oil recovery



Npp application for heat oil exploitation (Orimulsion)

Venuezuela

Enhanced brown coal quality

Enhanced brown coal quality

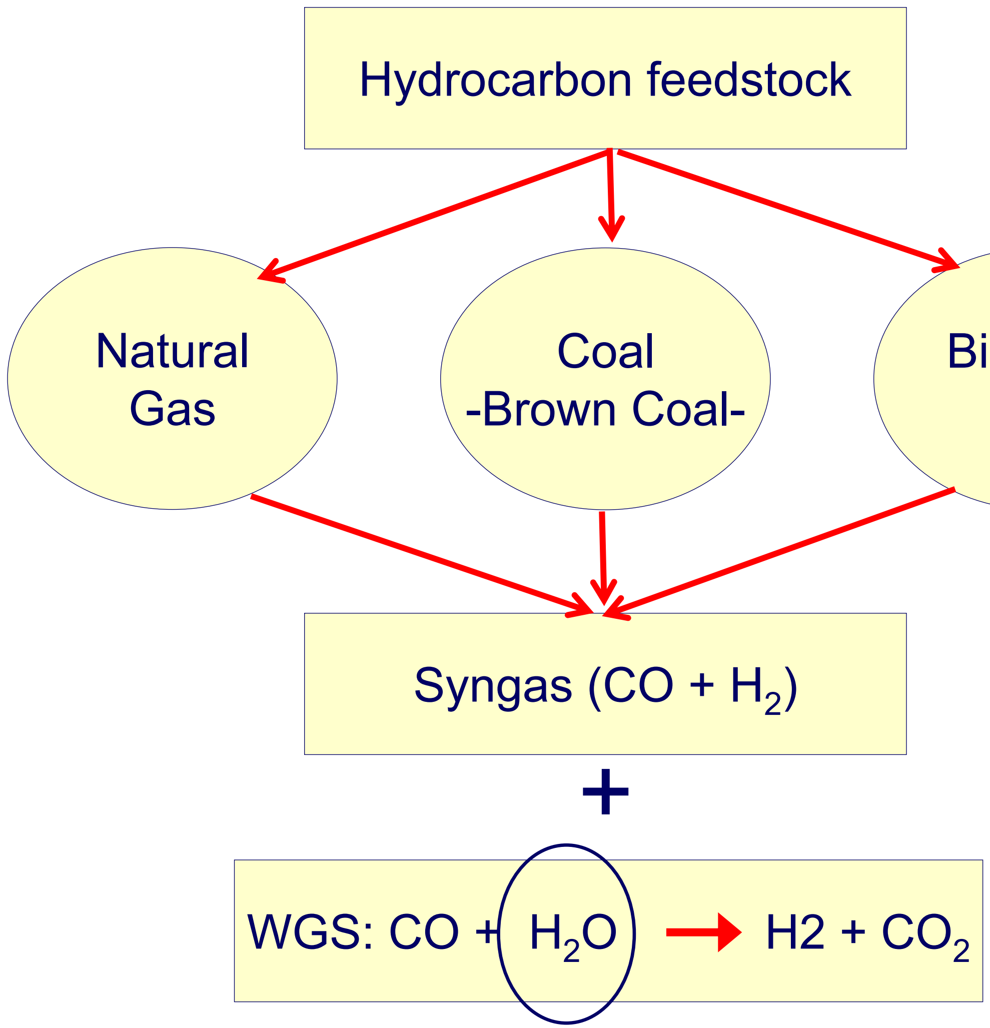
- **Lignite** is somewhere between coal and peat (used almost exclusively as a fuel for steam-electric power generation)

- The heat content ranges from 10 to 20 MJ/kg (9 to 17 million Btu per short ton)

- Typically has high moisture content, needs drying

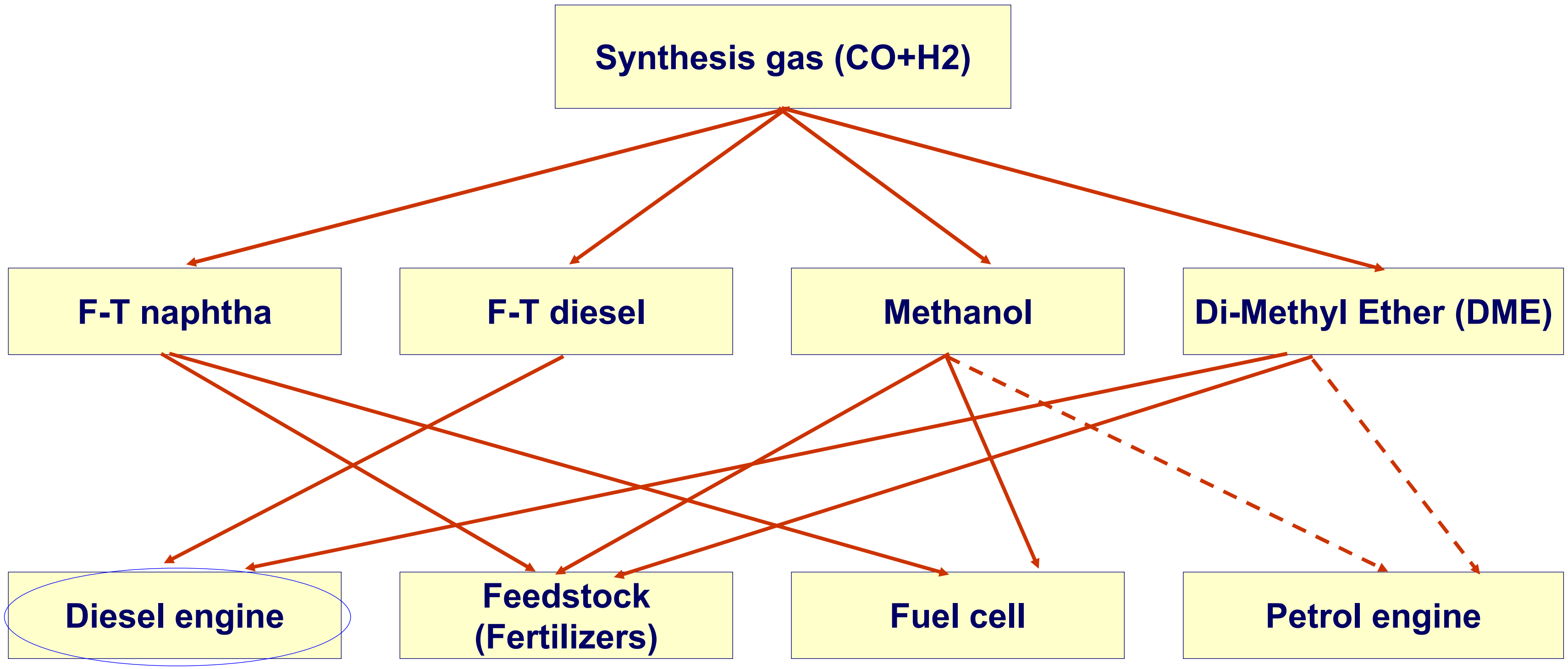
- Carbon dioxide emissions from brown coal fired plants are generally much higher than for comparable black coal plants

Enhanced brown coal quality



Enhanced brown coal quality

Syngas for methanol



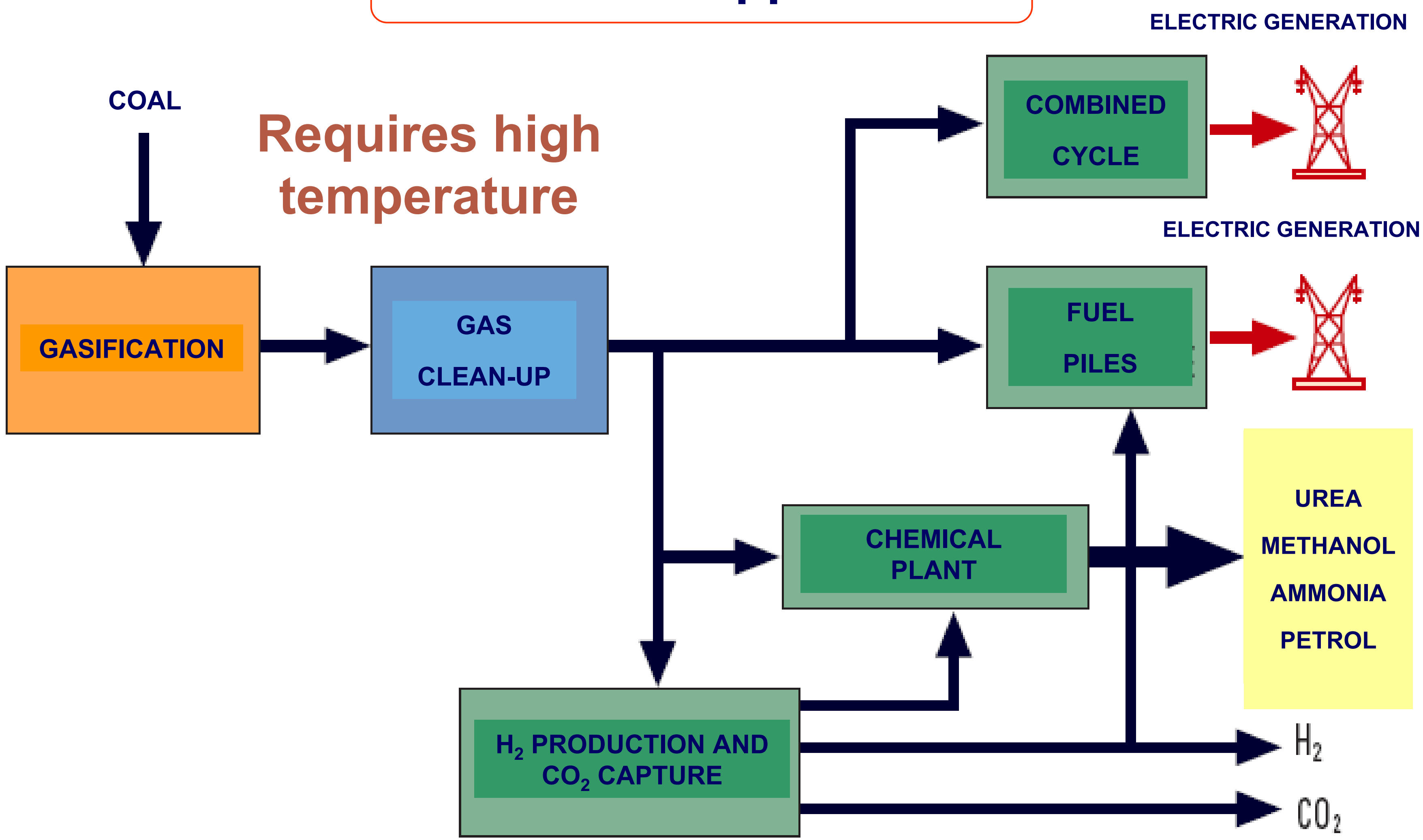
Enhanced brown coal quality

LARGE SCALE INTEGRATED PILOT PROJECTS						
PROJECT	LOCATION	MWth		START-UP	MAIN FUEL	REMARKS
		PC	CFB			
VATTENFALL	GERMANY	30		2009	LIGNITES	1 BURNER
TOTAL	FRANCE	30		2009	NG/HC	1 BURNER INDUSTRIAL BOILER
CIUDEN	SPAIN	20	30	2010	ANT./BIT./ PETCOKE	2+2 BURNERS
OXYBURNERS TEST FACILITIES						
B&W	USA	30		2007	BIT., SUB B, LIGN.	1 BURNER
OXY-COAL UK	UK	40		2008		1 BURNER
BOILERS REFURBISHMENT/RETROFITTING						
PEARL PLANT	USA	66		2009	BIT.	JUPITER TECHNOLOGY
CALLIDE	AUSTRALIA	90		2010	BIT.	-

Coal gasification

Coal Gasification

Gasification applications

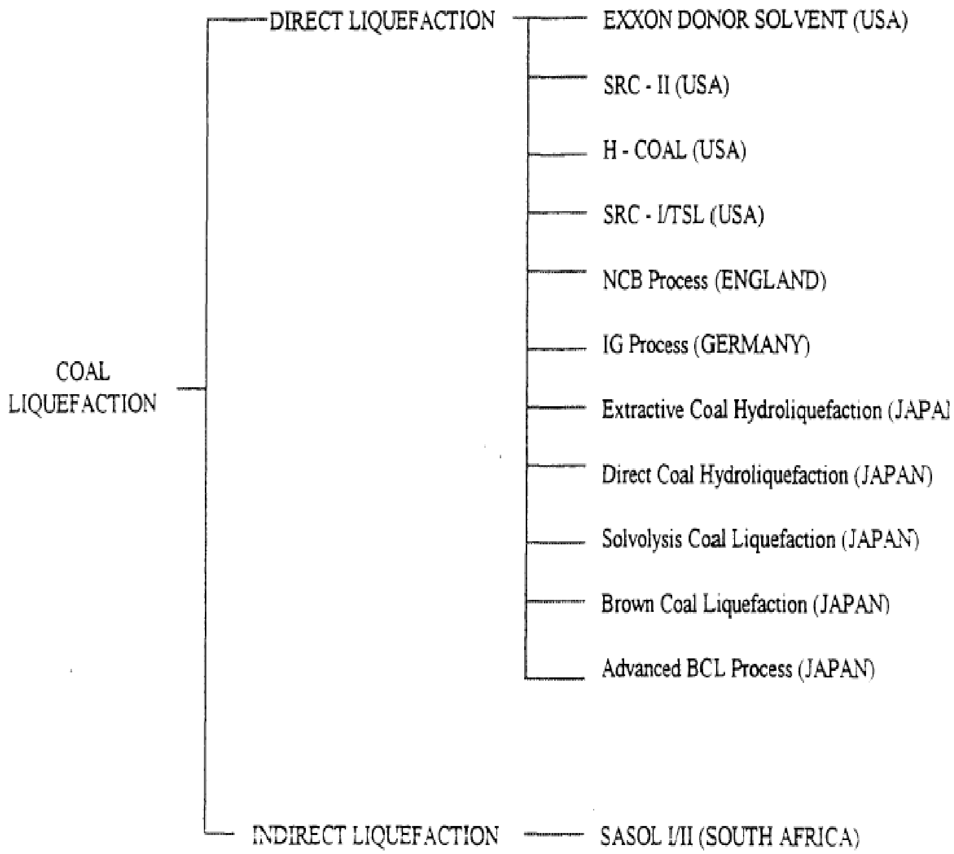


Coal Liquefactions

Coal Liquefaction

- A process to convert COAL from a solid state into liquid fuels, to provide substitutes for petroleum products.

- Large scale applications have existed in: Germany South Africa



➢ Efficiencies of different processes

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%

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**

…Thank you for your attention

International Atomic Energy Agency