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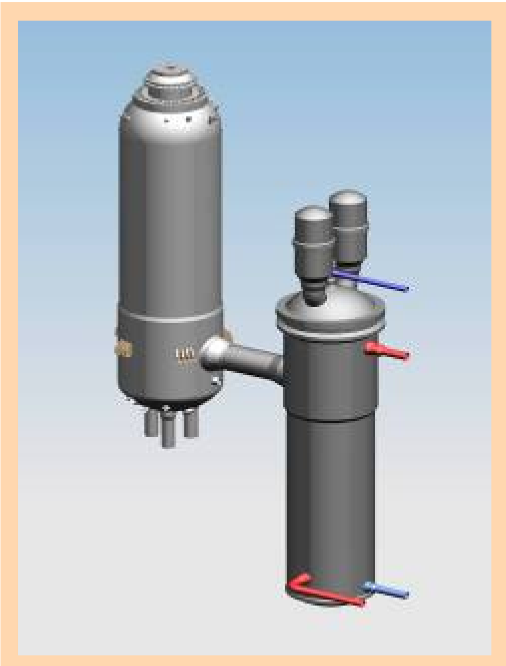
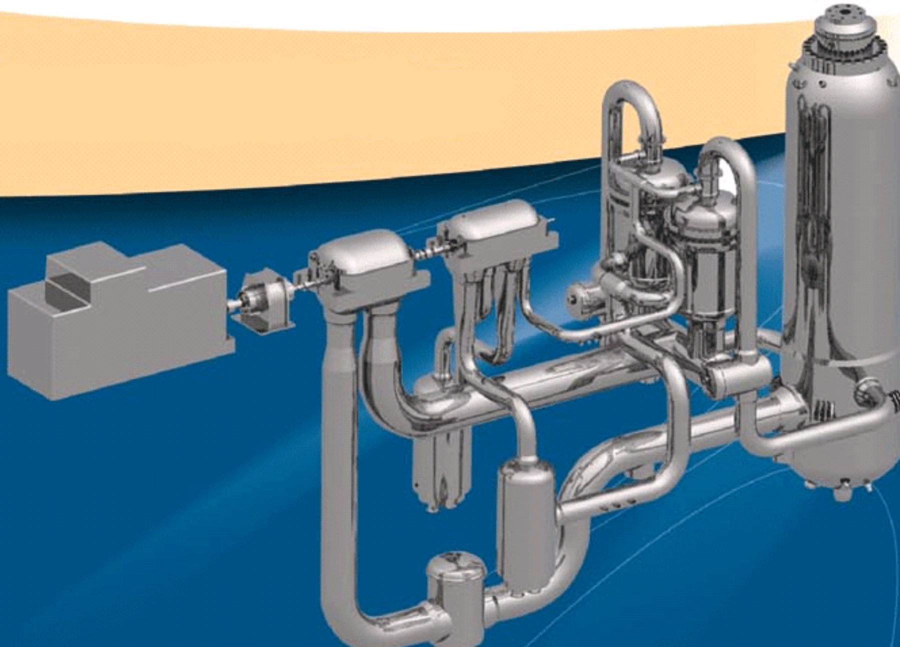




Process Heat Initiatives and a Focus on Hydrogen

Renee Greyvenstein
PBMR

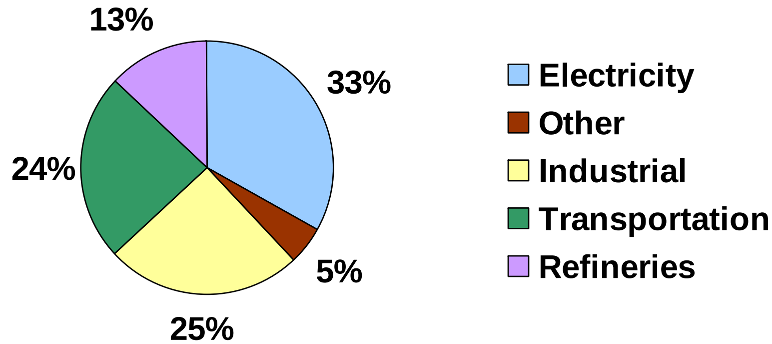
Ed Lahoda
Westinghouse Electric LLC

Nuclear Is Beyond Electricity

- **Nuclear power plants today supply ~16% of global electricity**

- **Process heat can expand nuclear applications to other energy sectors**
  - Industrial
  - Transport
  - Refineries
- **Process Heat Opportunity**
  - Stable process energy costs
  - Displace natural gas and other premium fuels
  - Reduce CO_2 emissions

World CO_2 Emissions by Sector

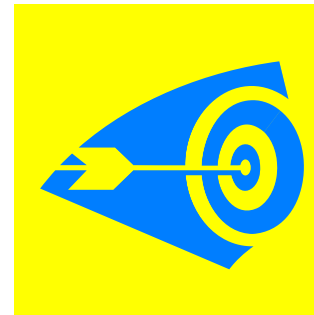


Process Heat Team

- **Shaw, Westinghouse and PBMR have teamed to produce clean, secure and economic hydrogen**

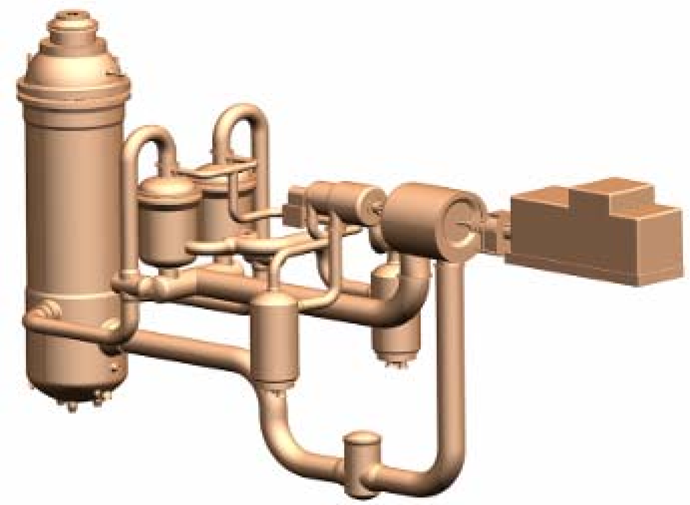
Why PBMR for Process Heat?

- **Right heat delivery temperatures (up to 900°C)**
  - Catalyst reactions (reforming, water splitting)
  - High pressure steam (oil sands and heavy oil recovery)
  - Can be extended beyond 900°C once IHX technologies available
- **Right size and outputs (400-500MWt)**
  - Matches industrial plant sizes
  - Matches incremental process heat demands
  - Modularity enables scalability
- **Timely market entry**
  - Builds on South African Demonstration Power Plant (DPP) Project
- **Enhanced Safety Features**
  - Small nuclear footprint
  - Allows proximity to customer facilities
  - Easier acceptance by process industry
- **Clean (no CO_2)**

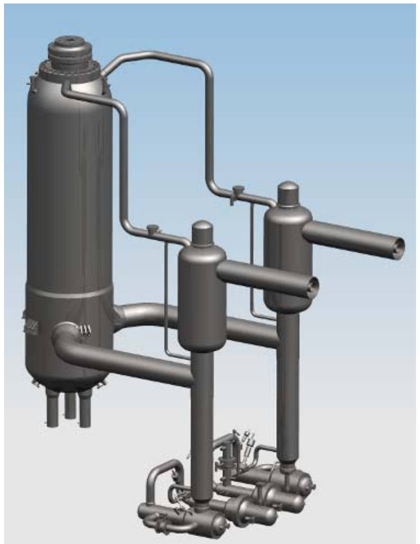


PBMR Process Heat Focus

- **First of Fleet Power Reactor**
  - Basic design completed; detailed design started
  - International supply team in place;
  - Extensive test programs underway
  - Construction scheduled 2009



- **Process Heat Plant (PHP)**
  - Builds on DPP reactor design
  - Produces heat up to 950°C
  - Ready for operation in 2016 to 2020 time frame
  - High temperature steam (400 to 500°C)
  - High temperature process heat (600 to 900°C)

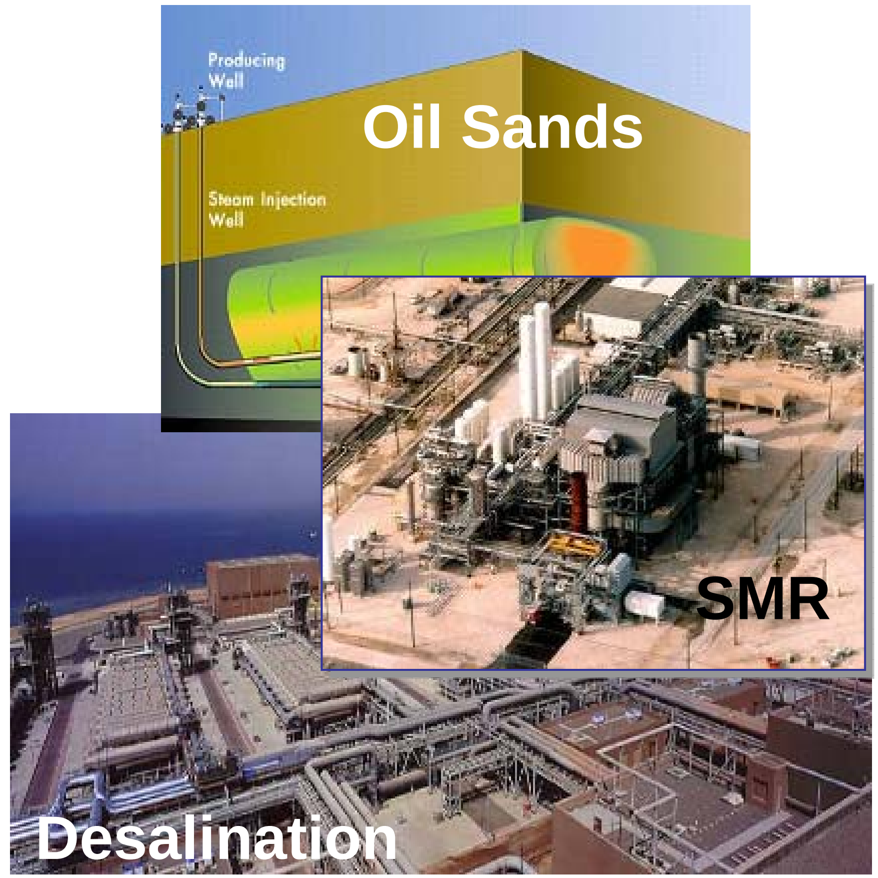


- **Next Generation Nuclear Plant (NGNP)**
  - Produces heat at 950°C for hydrogen production
  - Completed Preconceptual Design

Process Heat Applications

- **Interim Goal: Process Steam (400°C to 700°C)**
  - Oil Sands
  - Cogeneration
  - Heavy oil recovery
  - Desalination

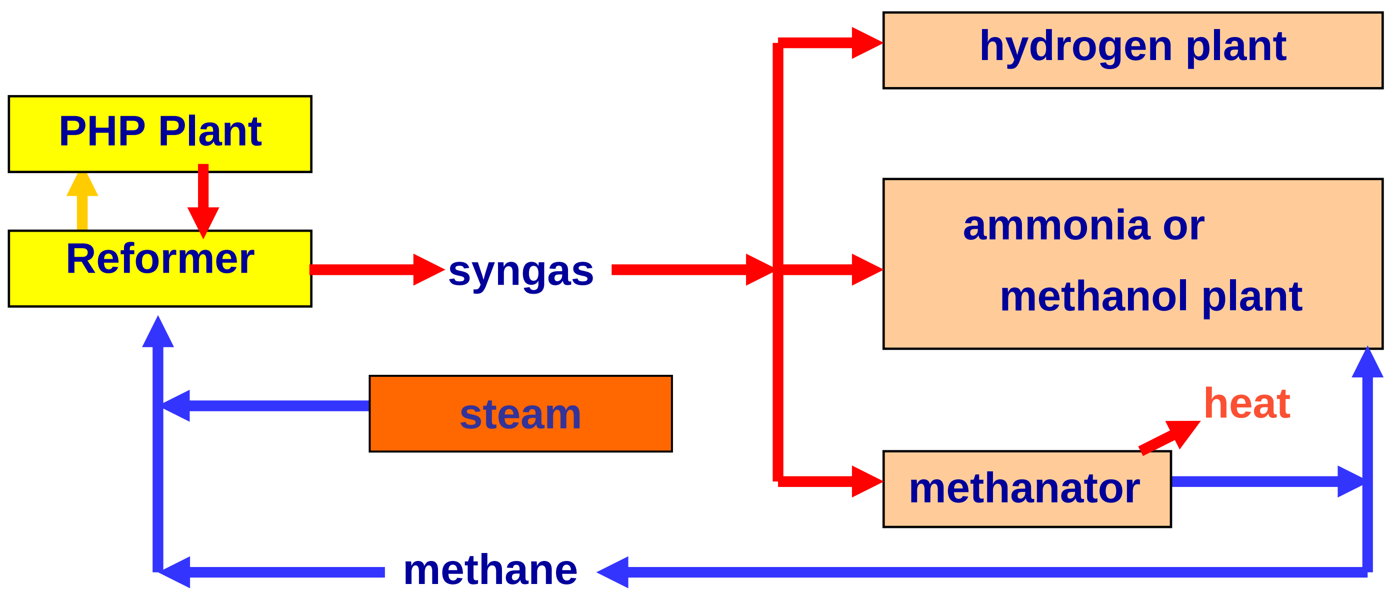
- **Key Long-term Goal: Hydrogen (600°C to 900°C)**
  - Steam Methane Reforming (Hydrogen, Ammonia, Methanol)
  - Water-Splitting (H_2 & O_2)
    - Bulk Hydrogen
    - Coal-to-liquids
    - Coal-to-methane



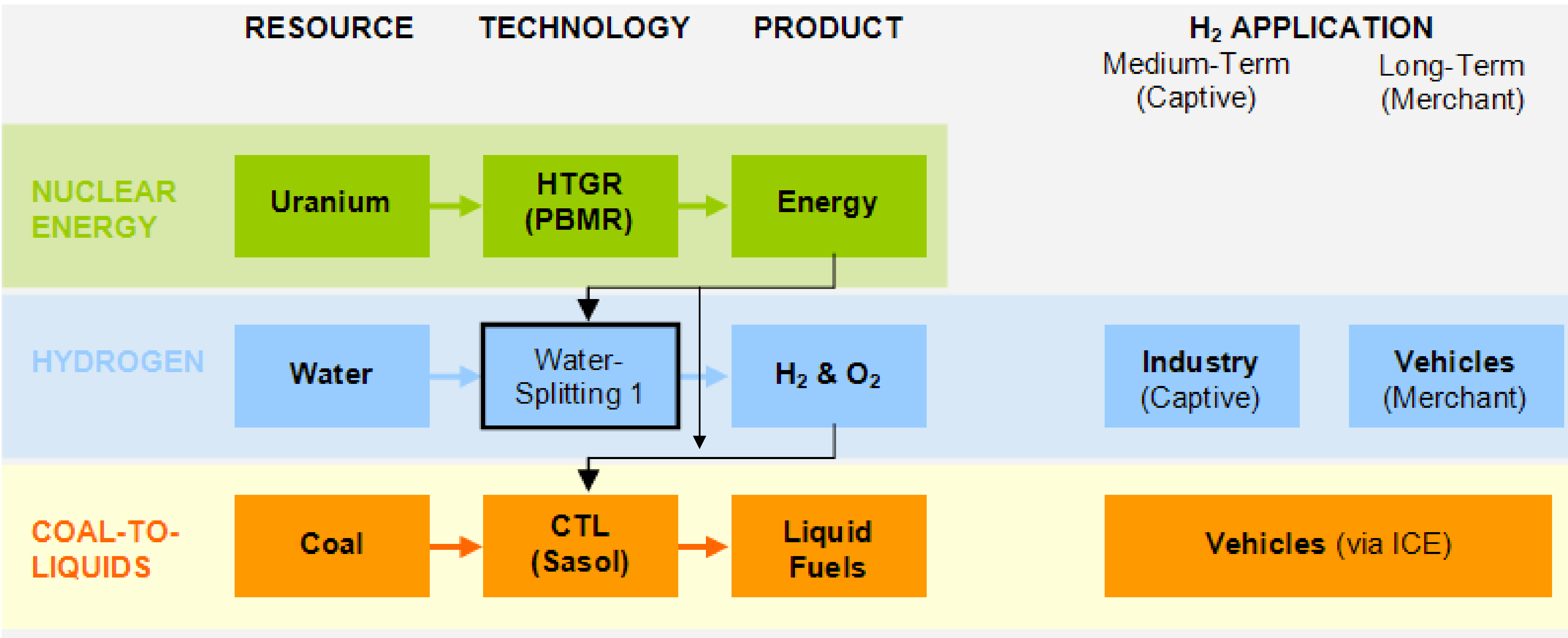
- **Reduce CO_2 emissions**
- **Displace premium fuels**
- **Increase lifetime of carbon resources**

Nuclear Steam Methane Reforming – Interim Goal

- **Reformer Reaction**
  - $CH_4 + H_2O \rightarrow CO + 3H_2$ (>800°C heat required)
- **PHP provides heat for reformer; displaces ~ 30% natural gas - eliminates flue gas CO_2 – most expensive to capture**
- **Remaining heat is used for steam or power co production**
- **Value of syngas expected to exceed projected plant costs**



Hydrogen from Water-Splitting Long Term Goal

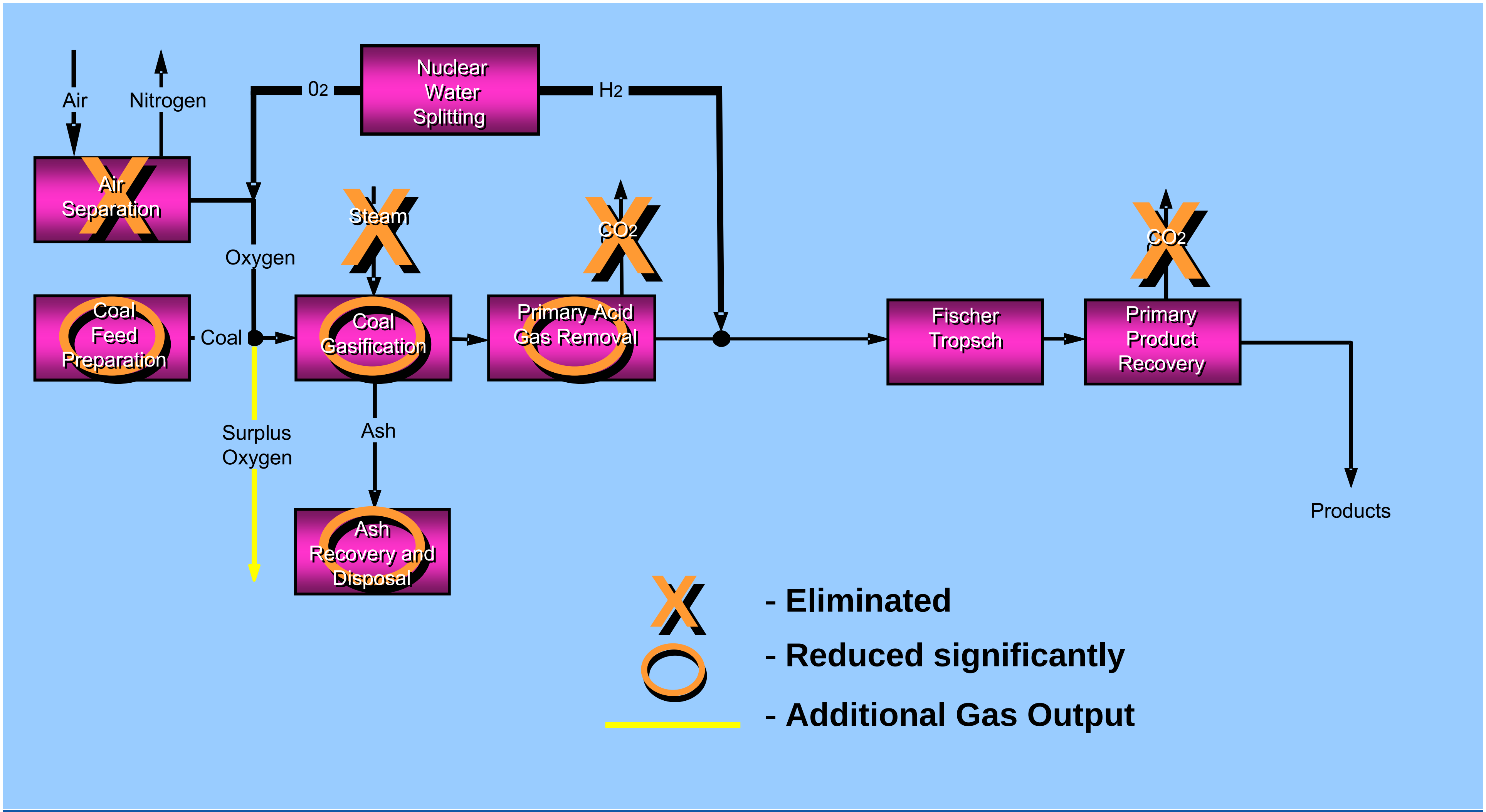


Coal-to-Liquids Concept

- **Initially developed in Germany in the 1920s**
- **Basis for coal-to-liquid fuel production by Sasol in the Republic of South Africa**
  - Provides ~30% of RSA gasoline and diesel fuel
  - Shaw/Badger is Sasol Technology partner
- **New CTL projects proposed**
- **CTL process is a significant user of hydrogen (coal gasification)**

Sasol South Africa, CTL Plant

Nuclear Water Splitting Simplifies Coal to Liquids



Market and Economics for Nuclear Water Splitting

- **Value of Nuclear Water Splitting for CTL**
  - Displace gasification capacity, oxygen plant and related facilities dedicated to producing needed hydrogen (roughly half of syngas)
  - Eliminate CO_2 production associated with converting half of coal to CO_2 just to make hydrogen
  - Reduce coal consumption roughly in half

- **Cost of Nuclear Water Splitting**
  - Water splitting consumes large amounts of energy; many reactors needed for each gasifier train (producing H_2 from hydrocarbons is easier than splitting water)
  - Replaces CO_2 intensive operation with capital intensive operation
  - Requires development of efficient, low cost water splitting process
  - Competition hinges on fossil fuel prices and CO_2 costs/credits

Nuclear Water-Splitting Concept

- **Several proposed Water-Splitting (WS) technologies evaluated**
  - Conventional Water Electrolysis
  - High-Temperature Steam Electrolysis
  - Hybrid Sulfur Process
  - Sulfur Iodine Process

- **At present, PBMR selected the Hybrid Sulfur Process as reference cycle:**

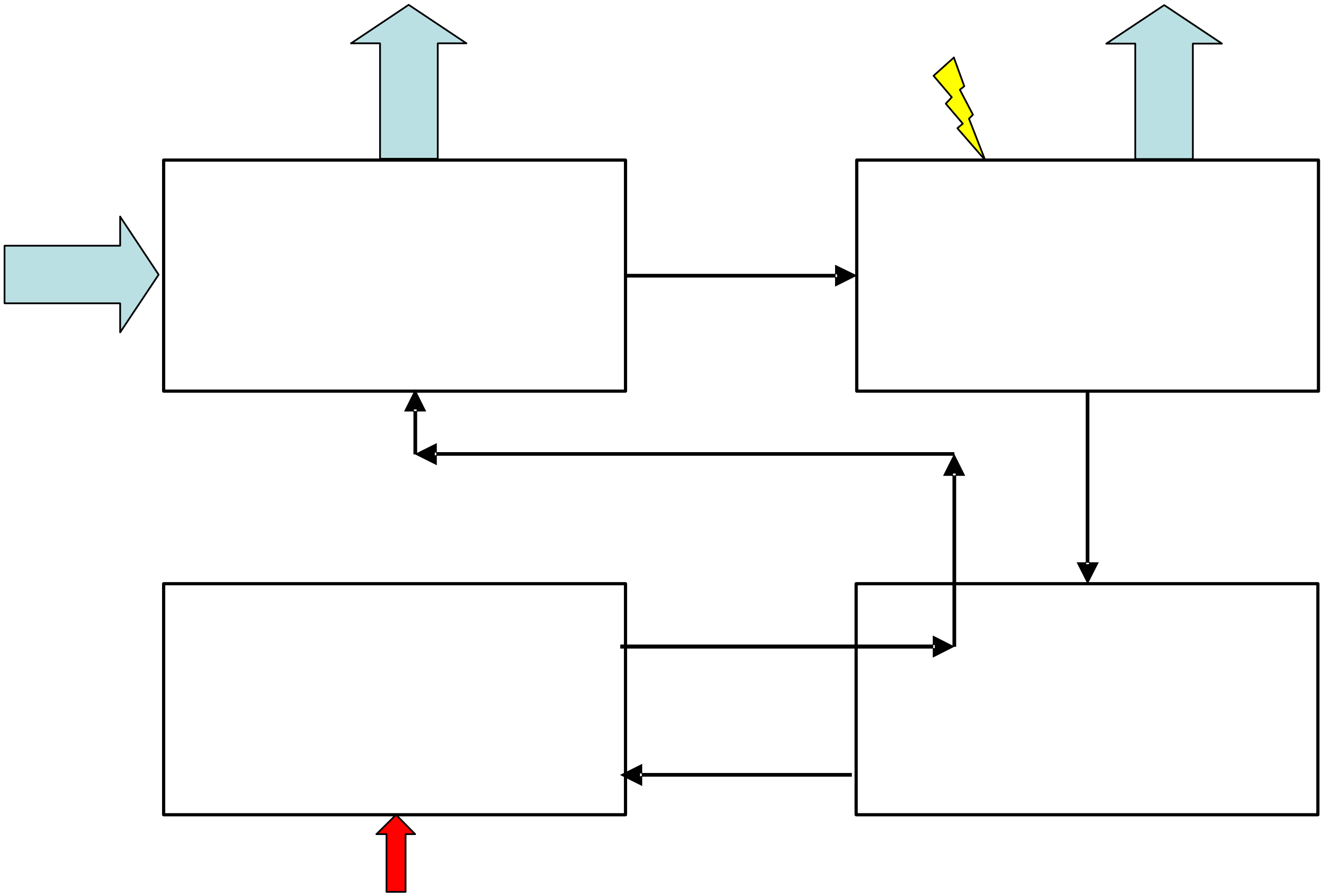
  $H_2SO_4 \rightarrow SO_2 + H_2O + ½ O_2$ (>800°C heat required)

  $2H_2O + SO_2 \rightarrow H_2 + H_2SO_4$ (electrolytic at 100°C)

  - Reasonably high efficiency
  - Defined flowsheet and thermodynamics
  - Lowest expected costs

- **However, technology development is required to commercialize Hybrid Sulfur (HyS) WS**
  - PHP team part of NGNP
  - Internal PBMR and Westinghouse Electric funds committed

Hybrid Sulfur Process Schematic

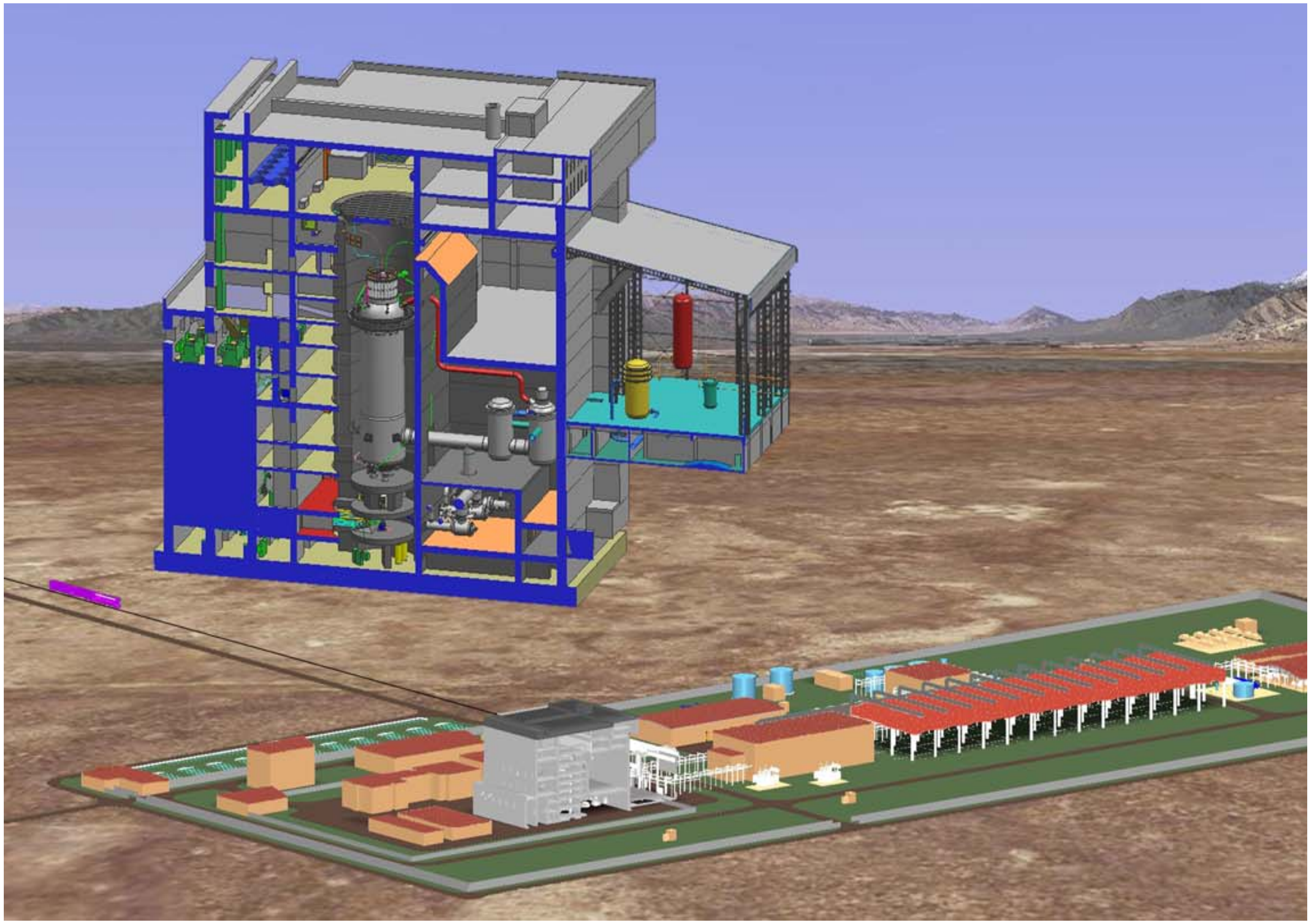


Hybrid Sulfur (HyS) History

- **Work started in 1973 (Westinghouse)**
- **Multi-year DOE project (1976) - pre-pilot bench scale demonstration by 1983**
- **Integrated, atmospheric pressure laboratory model constructed in 1978 (120 l/hr of H_2 bench scale process operated for ~140 hours)**
- **Advances since 1983:**
  - Equipment design and optimization (e.g., decomposition reactor)
  - Materials of construction (e.g., Nafion membranes, SiC)
- **Savannah River National Laboratory (SRNL) completed pioneering work on electrolyzer**
  - Successful electrolyzer test with Nafion membranes for 100 hours (May 2007)
  - Completed multicell stack electrolyzer demonstration @ 80 lph (March 2008)
  - Risk mitigation of electrolyzer technologies

NGNP Project

USA Department of Energy (DOE) initiative to develop a prototype plant to generate hydrogen using nuclear energy



Westinghouse

PBMR

Shaw®

AIR PRODUCTS

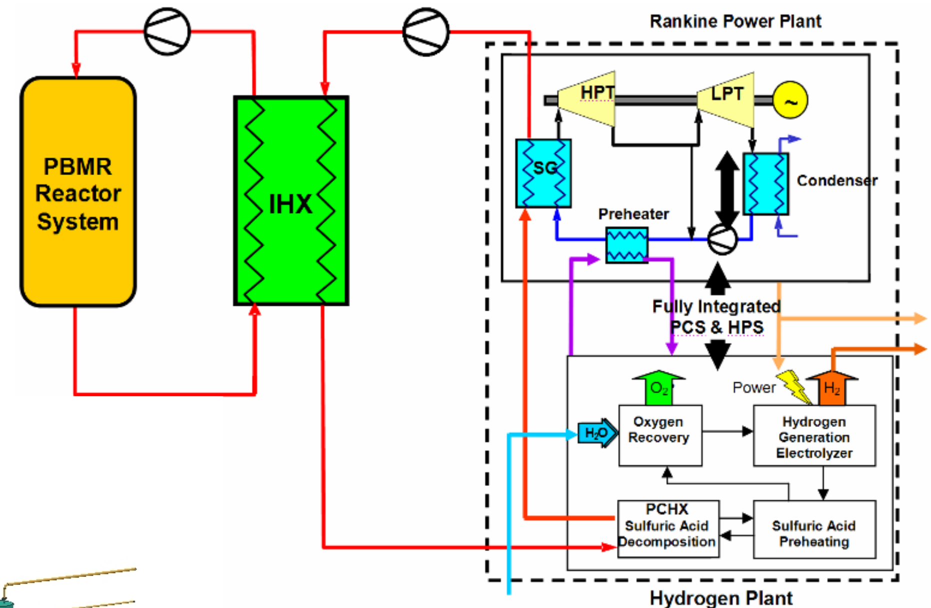
TECHNOLOGY INSIGHTS

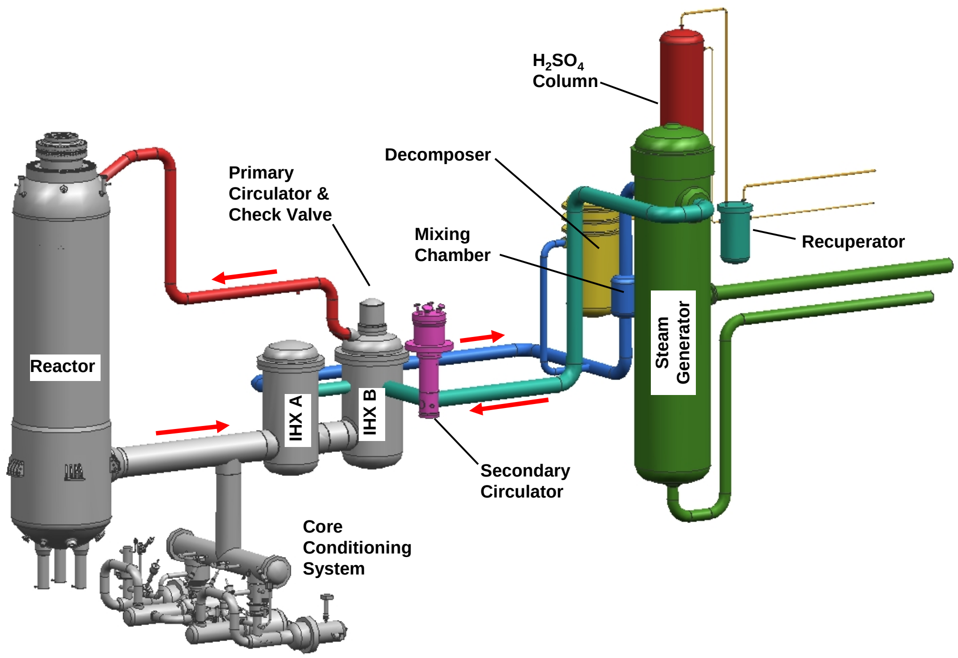
M-Tech industrial

Kadak Associates, Inc.

NFS NUCLEAR FUEL SERVICES, INC.

Nuclear Water-Splitting Concept for NGNP





PBMR and RSA Are Committed to Nuclear Hydrogen Generation

HYDROGEN BUSINESS PLAN

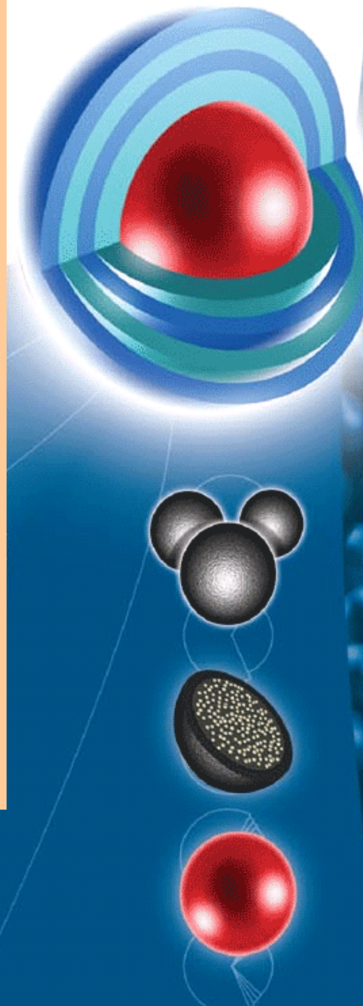
#063555

15 June 2007

The consortium is pleased to present to Department of Science and Technology an unsolicited hydrogen production business plan which incorporates a strategic vision for national innovation

Summary

- PBMR provides process heat and electrical power for wide variety of applications
- Near term initiatives are in oil sands bitumen production and other steam and cogen applications
- New technology developments underway for nuclear water splitting as part of NGNP
- Innovative PBMR design, modular construction, and simplification of nuclear licensing leads to development of public support and positive government policies
- Recognition of PBMR as a CO_2 free, stable cost energy source will increase public support for PHP applications and hydrogen generation



Thank You