Nuclear Hybrid Energy Systems

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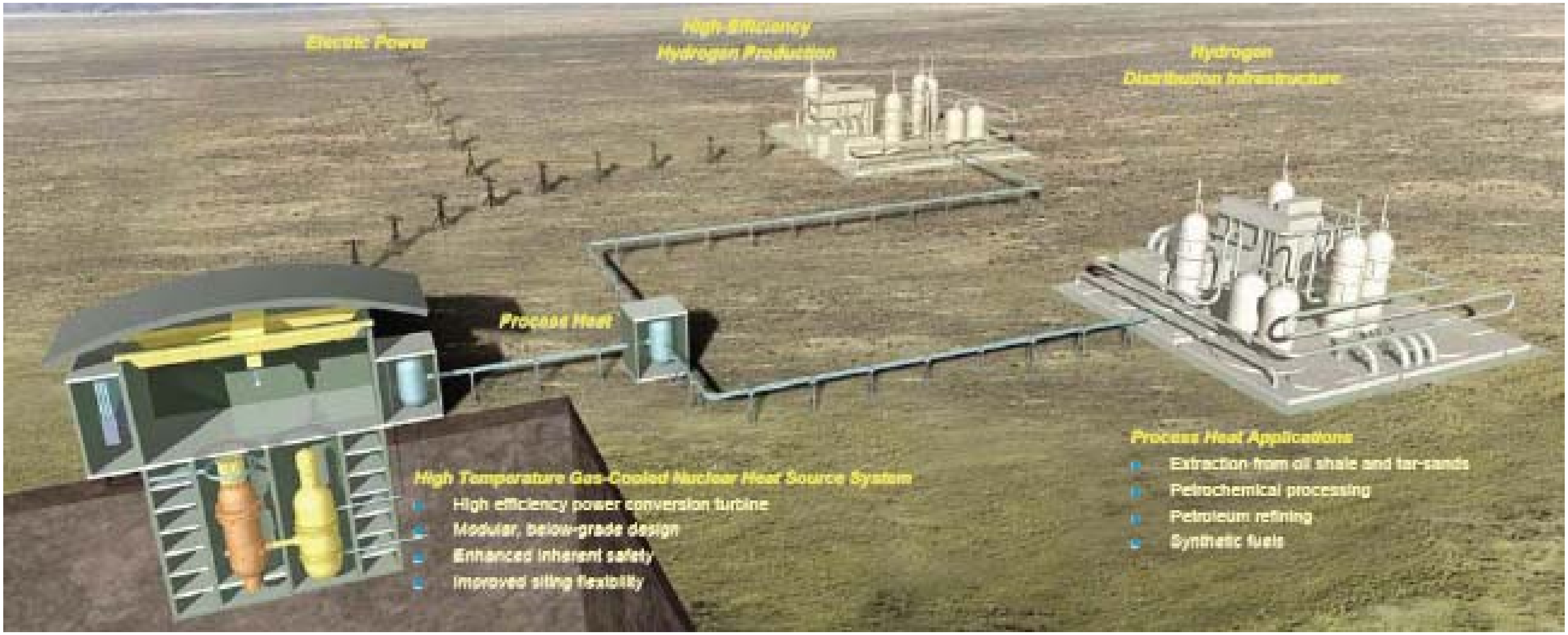
The Vision: Creating Clean Energy Islands



Carbon Management → Hybrid Energy Systems → Strategic Energy Islands = Energy Security

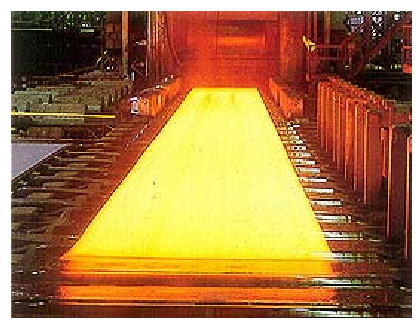
Carbon Management ↑ Production flexibility and efficiency through carbon lifecycle management

Hybrid Energy Systems ↑ Those systems that combine two or more primary energy and/or carbon resources to produce one or more energy products

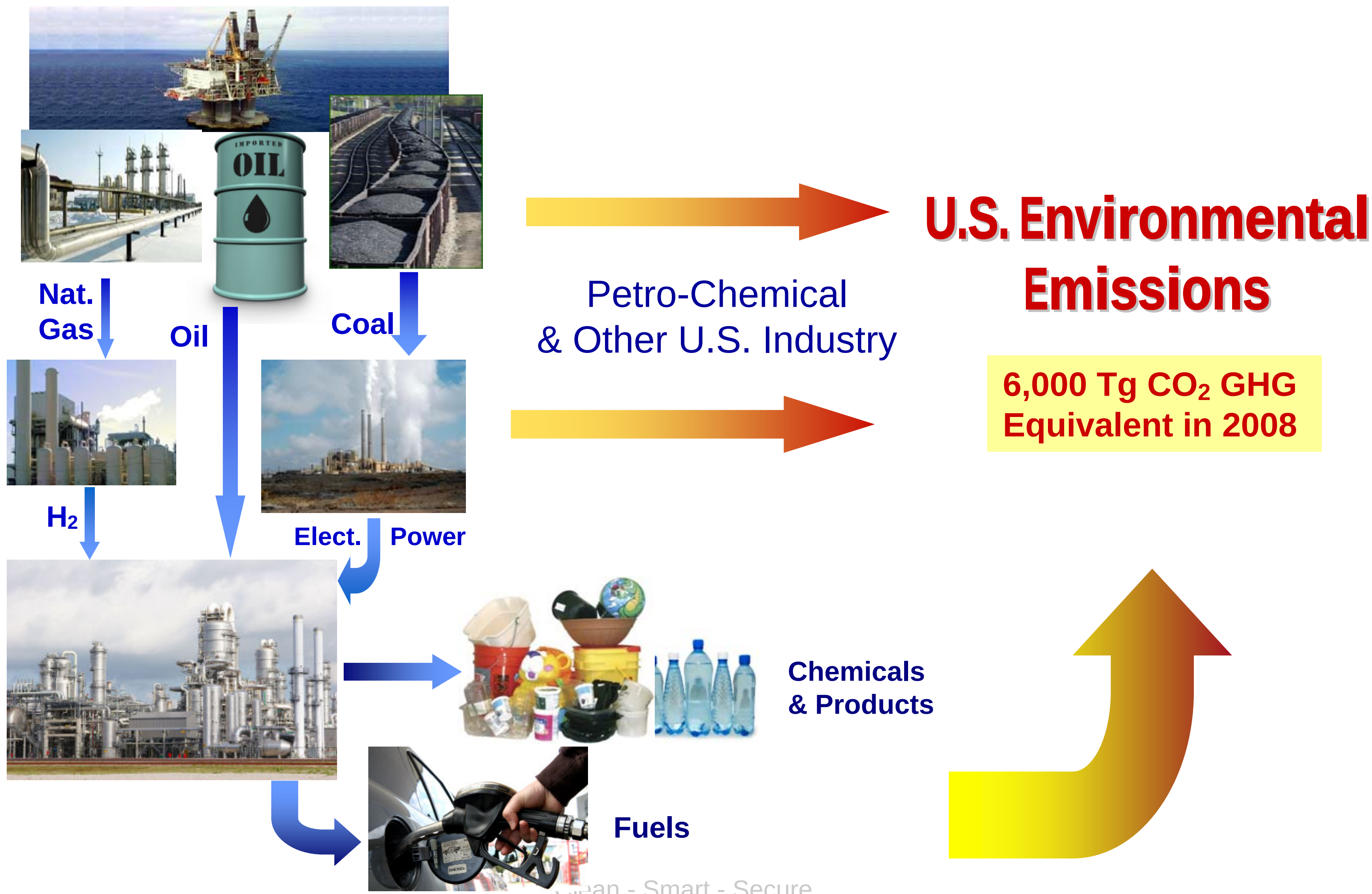
Strategic Energy Islands ↑ Coupling of strategic energy resources with polygeneration stations yielding liquid fuels, electricity, and chemicals

Major U.S. Industrial Energy Users

- **Petro-Chemical**
  - Resource extraction
  - Transportation fuels
  - Chemicals, plastic and paper products
- **Agriculture**
  - Production using heavy machinery
  - Ammonia and urea fertilizers from natural gas
- **Mining**
  - Electrical machinery for subsurface extraction
  - Heavy duty vehicles
  - Transportation
- **Manufacturing**
  - Steel refineries and associated auto and appliance manufacturers
  - Glass production
  - Cement kilns



Energy and Products Based on Fossil Fuels



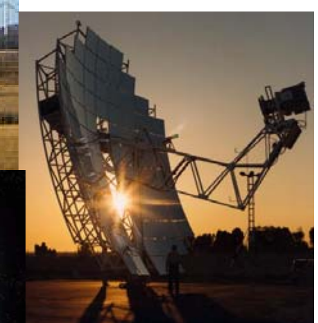
New Realities of Energy

Today’s paradigm

- Fossil energy continues to be the lowest cost / lowest risk alternative to energy demand
- U.S. and Europe have provided economic incentives to develop nuclear power, renewable, solar, and wind energy

Emerging paradigm

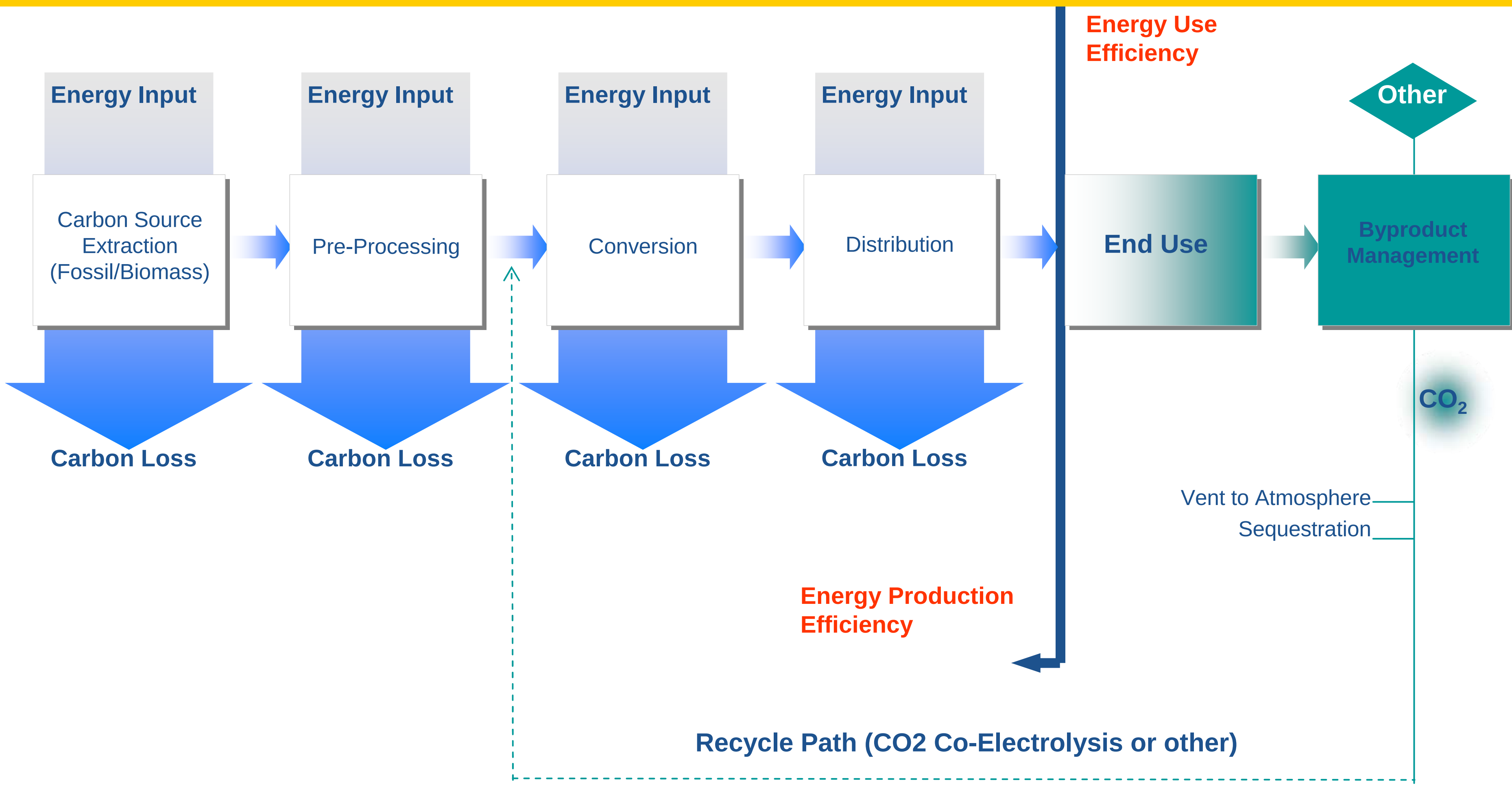
- Increasing cost of energy provides impetus to implement energy efficiency and alternative clean energy.
- As carbon emissions are tied to climate change, federal regulations are likely to favor more “green” energy production
- Domestic energy production will lead to greater national security



Economic stability is not always about price.

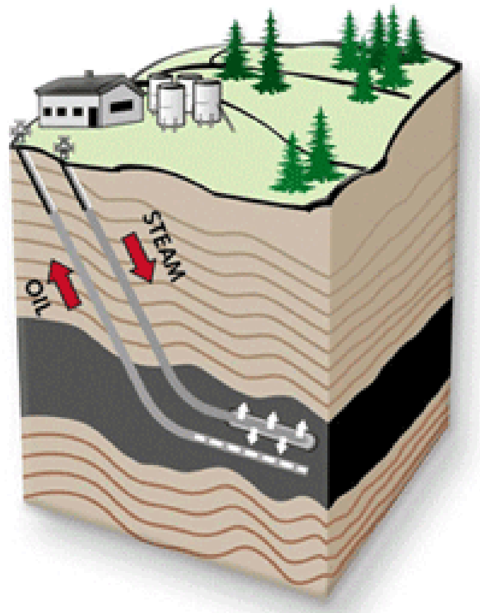
Production Efficiency and Flexibility through Carbon Lifecycle Management

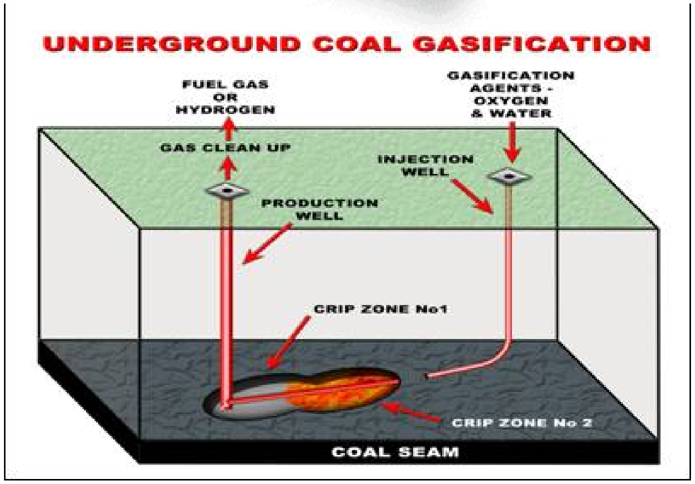
The Carbon Lifecycle in Energy Production and Use



Resource Extraction

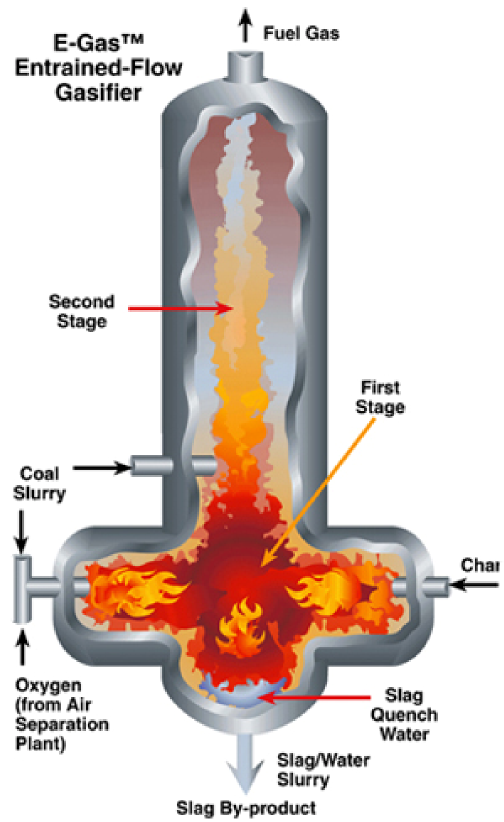
- ~930° F (500° C) Steam
  - Open mining of bitumen and
  - Steam assisted gravity drain (SAGD)
  - In-situ oil sands mobilization
  - Oil shale devolatilization and production
- Hydrogen
  - In-situ bitumen, oil sands cracking and hydrogenation
  - Ex-situ product upgrading
- Oxygen
  - Underground coal gasification
- Electrical Power
  - Mining and extraction
  - Compressors
  - Freeze-wall





Feedstock Preparation and Processing

- Process heat
  - Biomass and low-rank coal drying
  - Water treatment
  - Pyrolysis of heavy crudes, and biomass
  - Steam reforming / hydrothermal gasificatior
  - Steam methane reforming
  - Super-critical water oxidation
- Oxygen
  - Gasification of coal, biomass, and coke
  - Oxy-combustion for higher process heat



Transportation Fuels Refining

- Refinery ~400 – 930° F (200 – 500° C)
  - Distillation
  - Catalytic hydro-cracking
  - Hydro-treating
- Refinery ~930 – 1,292° F (500 – 700° C)
  - Coking
  - BTX catalytic cracking
  - Catalytic reforming
- Large hydrogen demands
  - Gasoline and diesel have higher hydrogen content than crude
  - Steam methane reforming
  - Use LTE or HTSE

7% of U.S. Energy

Nuclear Assisted Chemical Synthesis

- Chemical Industry consumes nearly 4% of U.S. Energy
  - ~700 million bbl of crude equivalent
  - ~9% of total crude oil use
- Ethylene and propylene
  - Steam cracking at ~1,500 – 1,600° F (815 – 870° C)
- Styrene
  - Dehydrogenation of ethyl benzene at ~1,170° F (630° C)
- Ethyl benzene
  - Friedel-Crafts Alkylation at ~194 - 790° F (90 – 420° C)
- Gasification
  - Produce methanol feedstock and derivatives
  - Ammonia and product derivatives

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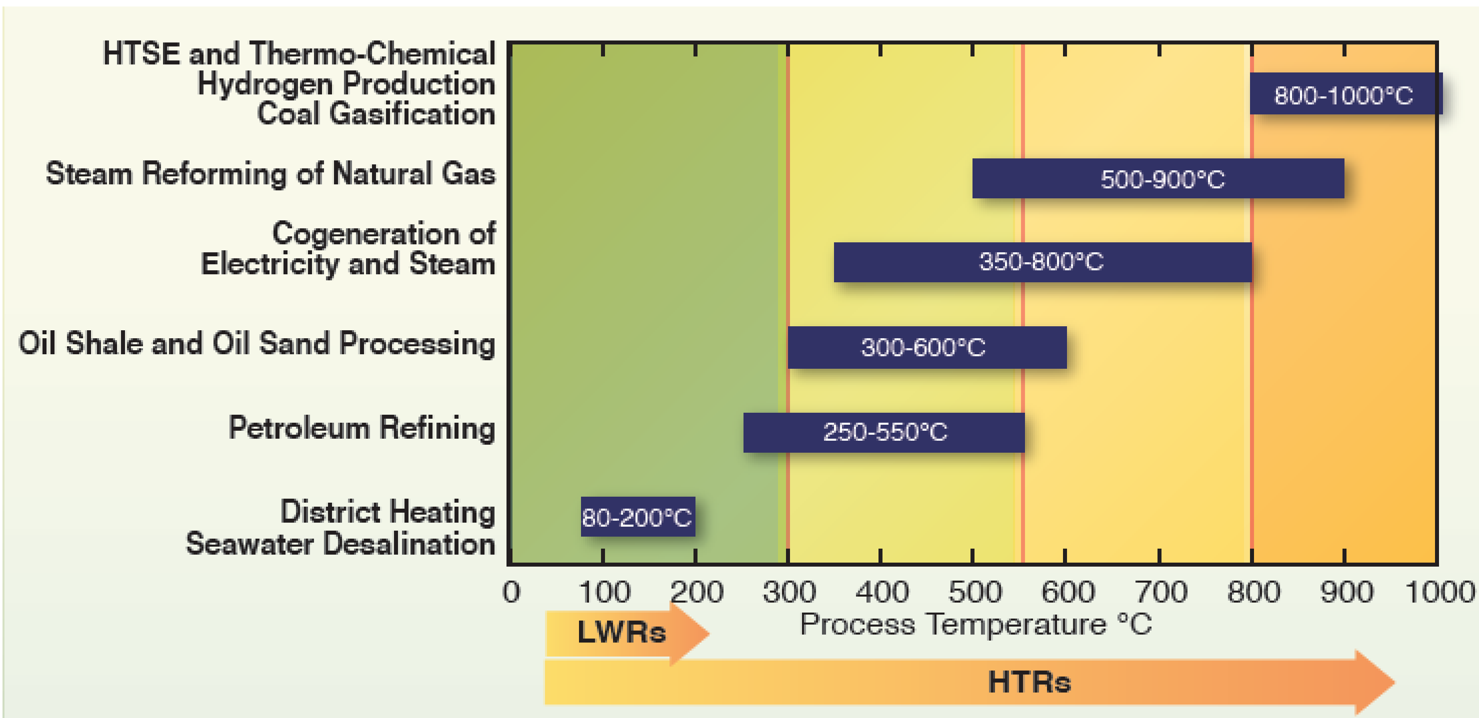
Process Heat From Current and Next Generation Nuclear Reactors

Partial List of Process Applications



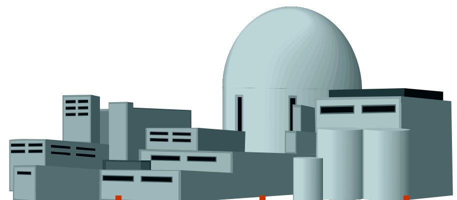
Nuclear-Fossil Hybrid Energy System

Carbonaceous Feedstock:
Fossil-Fuel
Biomass
Waste Materials

Water:
Surface
Saline
Effluent

Renewable

Base-load Nuclear Plant



Electric Power

Heat

O_2

H_2

Hydrocarbon Conversion Process

CO_2 Recycle

Products:
High energy fuels
Chemicals
Electricity
CO_2

Synthetic Fuels: Beyond Conventional Oil

Optimal Polygeneration of Products

Hydrogen

Near term
- natural gas
- LT electrolysis

Long term
- HTS electrolysis
- **Thermo-chemical water splitting**

Carbon

Near term
- natural gas
- **coal**
- biomass

Long term
- **coal**
- Oil sands
- Oil shale
- recycled carbon (CO_2) with HTR

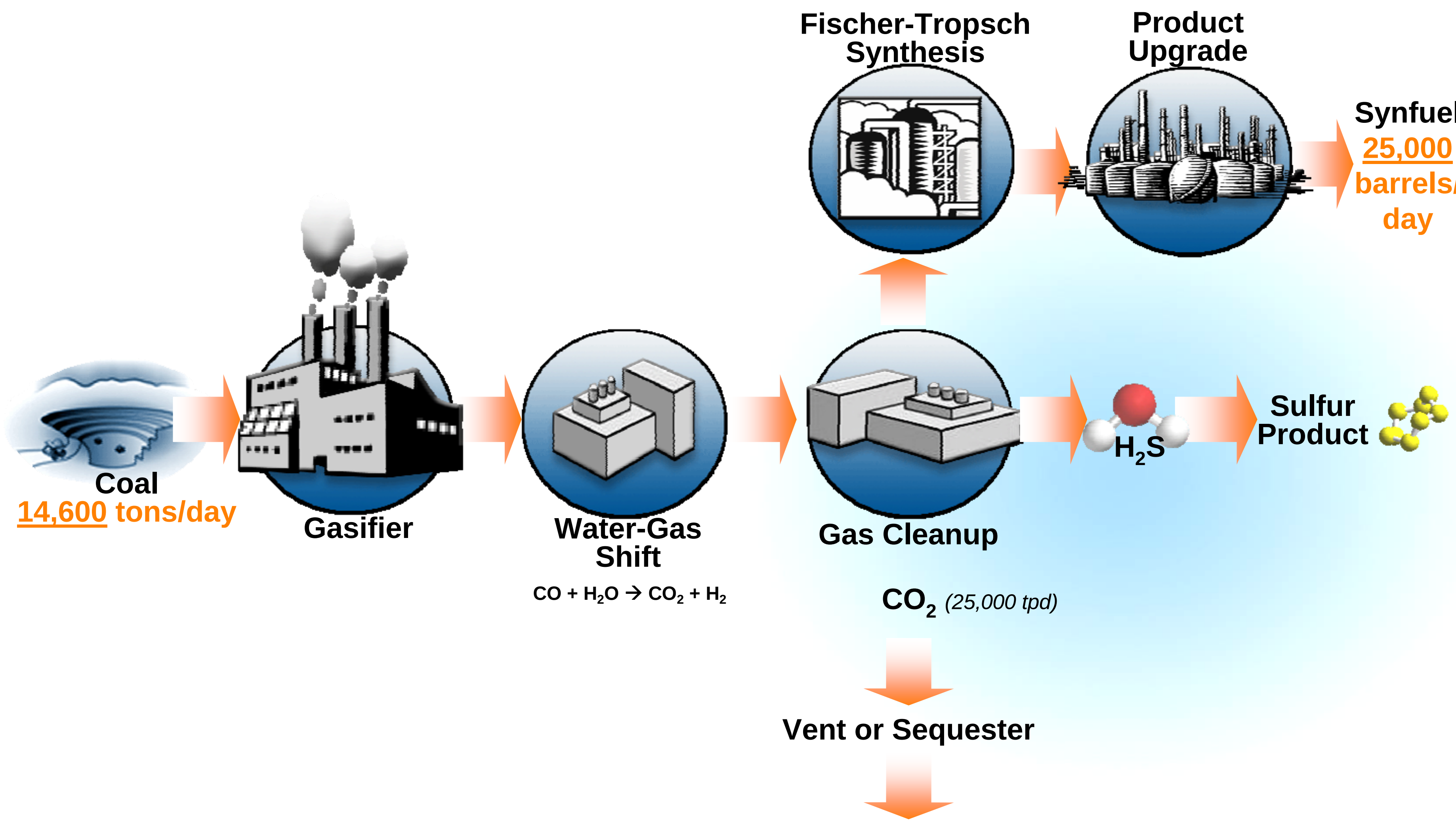
Energy

Near term
- **Fossil**

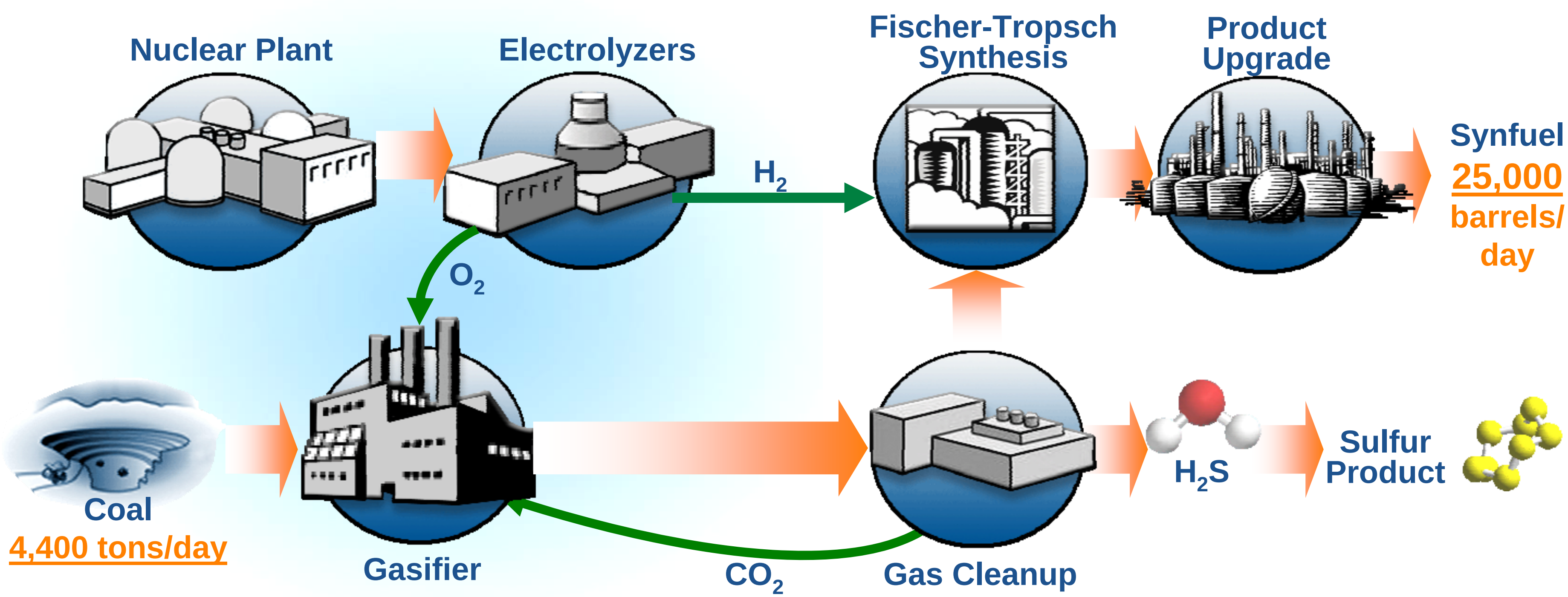
Long term
- **HTR**

Expanded uses of nuclear energy optimizes the carbon cycle

Conventional Fossil-Fuel Coal to Liquid



Nuclear Hybrid Coal to Liquid



- Hybrid systems use 70% less coal
- Little carbon is converted to CO_2
- Small amount of CO_2 is recycled to Gasifier
- No CO_2 emissions

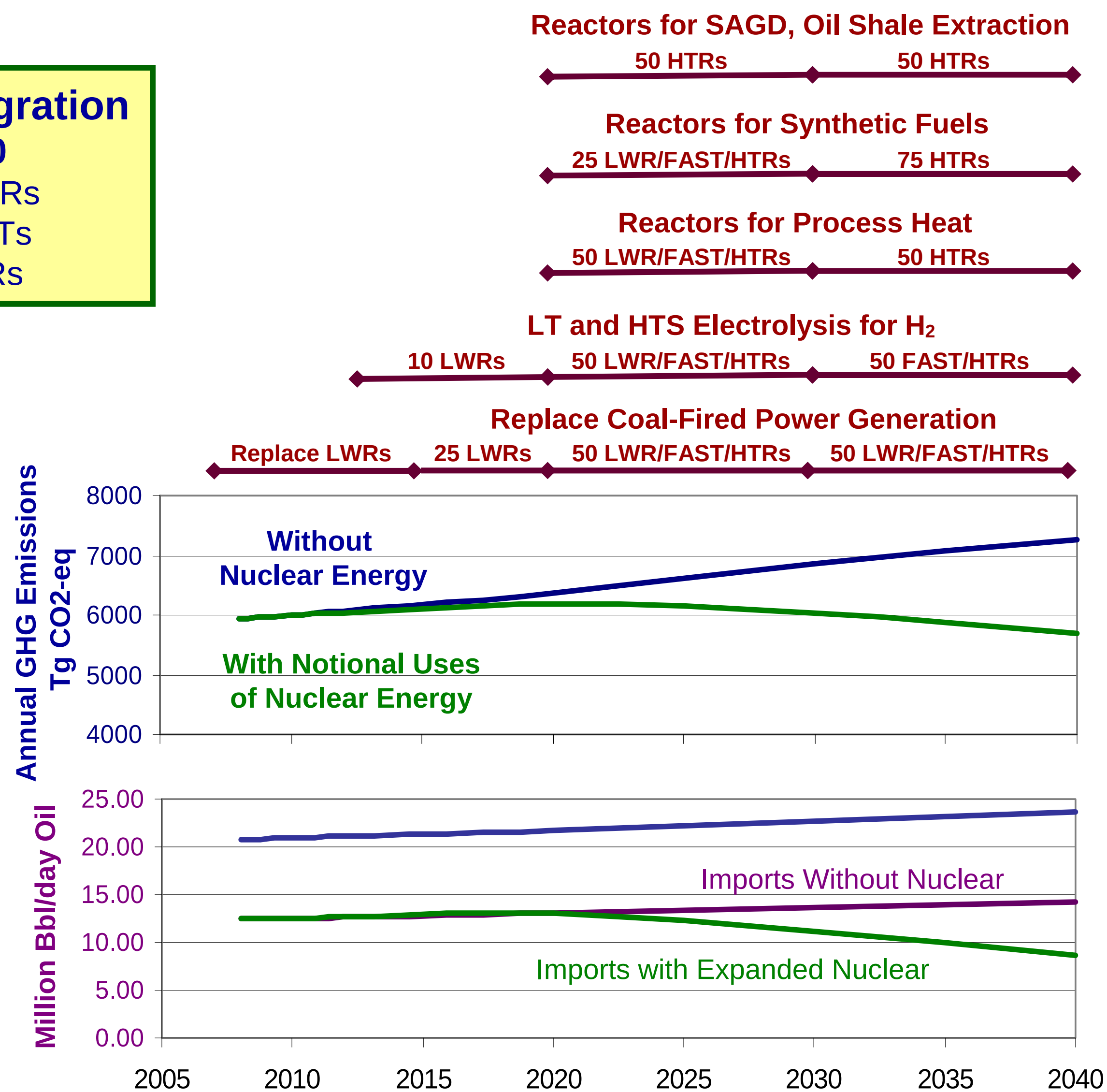
Traditional Coal-to-Liquid

- ***Good News:*** **In today's fundamentally changed global energy market, traditional CTL is a cost competitor with petroleum derived fuels**
- ***Bad News:*** **Generating hydrogen and oxygen to react with coal derived syngas produces copious quantifies of the greenhouse gas CO_2**
- ***Bad News:*** **Carbon Sequestration is not ready for commercial deployment**
- ***Good News:*** **There is another clean coal technology**

Nuclear-Fossil Energy Nexus

Theoretical Integration
2010 – 2040
1,500 MWe LWRs
600 MWe FASTs
600 MWe HTRs

- **~1,500 reduction in GHG emissions**
- **>15-20% reduction in fossil fuels**
- **> 30% reduction in GHG emissions**
- **> 5-15% reduction in fuel cost**



Hybrid Energy Systems – Ready and Adaptable

- **Hybrid CTL systems are flexible**
  - Include only one hybridization (nuclear + fossil CTL) or a suite of renewable energy / carbon inputs to further optimize energy production efficiency
  - Vary output depending upon market demand or national priorities – Gasoline and Gas/Electric Hybrids today Plug- in Hybrids tomorrow Hydrogen Fuel Cells later
- **Hybrid systems today open the possibility of expanded use of intermittent clean energy sources – wind, solar**
  - Heart of system is a standard NRC licensed nuclear reactor
  - CTL plants can be used to firm the grid, enhancing the attractiveness of renewables
- **Hybrid systems can accommodate new technologies in the future**
  - Individual processes can be upgraded as new technology is available
  - High Temperature Gas Reactor, can be co-located with original LWR

Ability to Start Today with Available Technologies – New LWRs and water electrolysis

Nuclear Hybrid Energy Parks Market Insertion—Deployment Timeframe

Providing Synthetic Transportation Fuels, Hydrogen/heat for Biofuels, Electricity for Electric Hybrid Vehicles, and Process Chemicals/heat for Industry

2015
LWR Driven Coal-to-Liquids Renewables insertion
1 evaluation facility
(100,000 BBL/day liquids & 250 MWe)

2030
* Advanced nuclear Coal-to-Liquids
With full biomass / renewable insertion
20 energy parks, 1 evaluation facility
(1 Million BBL/day liquids, 6,000 MWe, H_2 for transport,
Suite of chemical products)

2050
* Expand to
60 energy parks,
1 evaluation facility
(4 million BBL/day liquids, 18,000 MWe, H_2 for transport,
Suite of chemical products)

2060
* Expand to
100 energy parks,
1 evaluation facility
(10 million BBL/day, 30,000 MWe, H_2 for transport,
Suite of chemical products)

Today: High Carbon Intensity
Foreign Dependent
Trillions $ to foreign economies

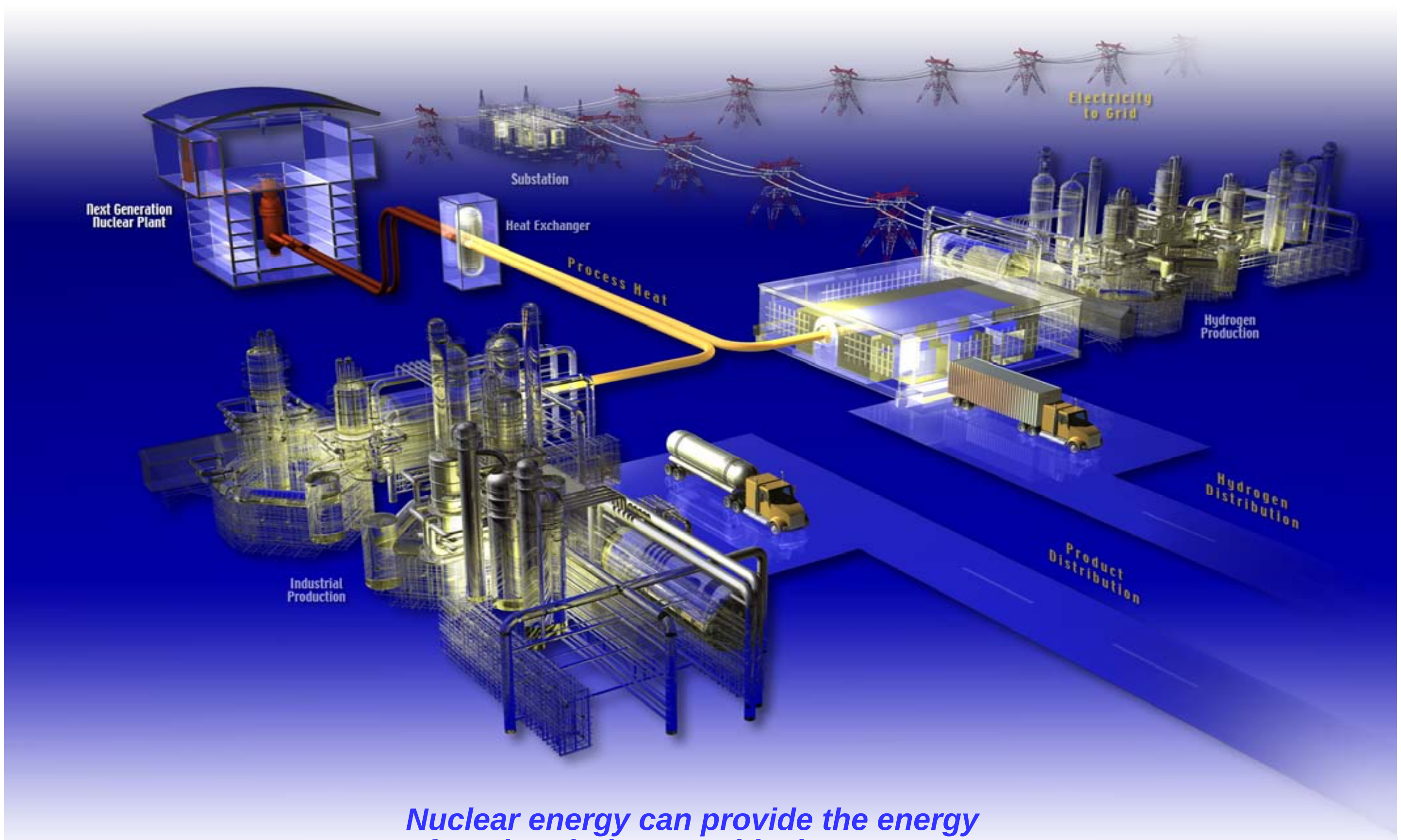
Low Carbon Intensity
Domestic Dependent
Trillions $ to U.S. economy

Hybrid Energy Systems combine nuclear, fossil, and renewables in a single plant *(Strategic Hybrid Energy Park)*

Hybrid Energy Park Benefits
- Produce fuels, electricity & chemicals
- Revolutionize transportation
- Lower carbon footprint
- **Utilize local, secure resources**

A Rational Transition to Energy & Environmental Security

Expanded Uses of Nuclear Energy



Nuclear energy can provide the energy of modern industry achieving; Environmental Sustainability, Economic Stability, and Resource Security through system optimization.