INL High School Physics Teachers Workshop

July 11, 2011

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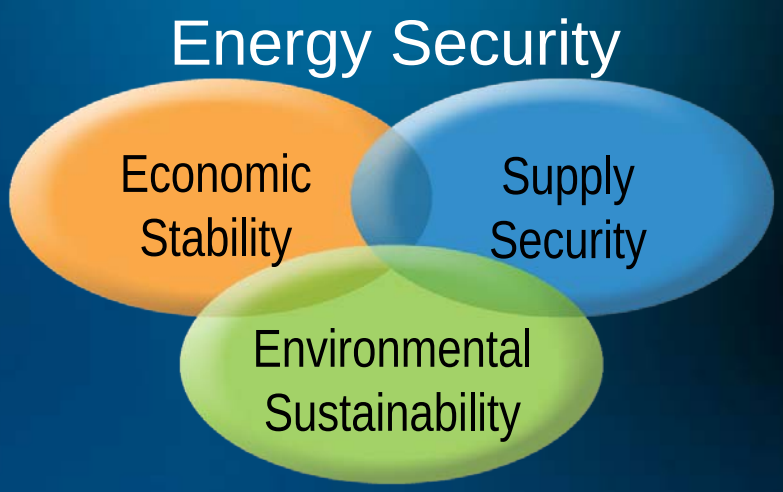
Idaho National Laboratory



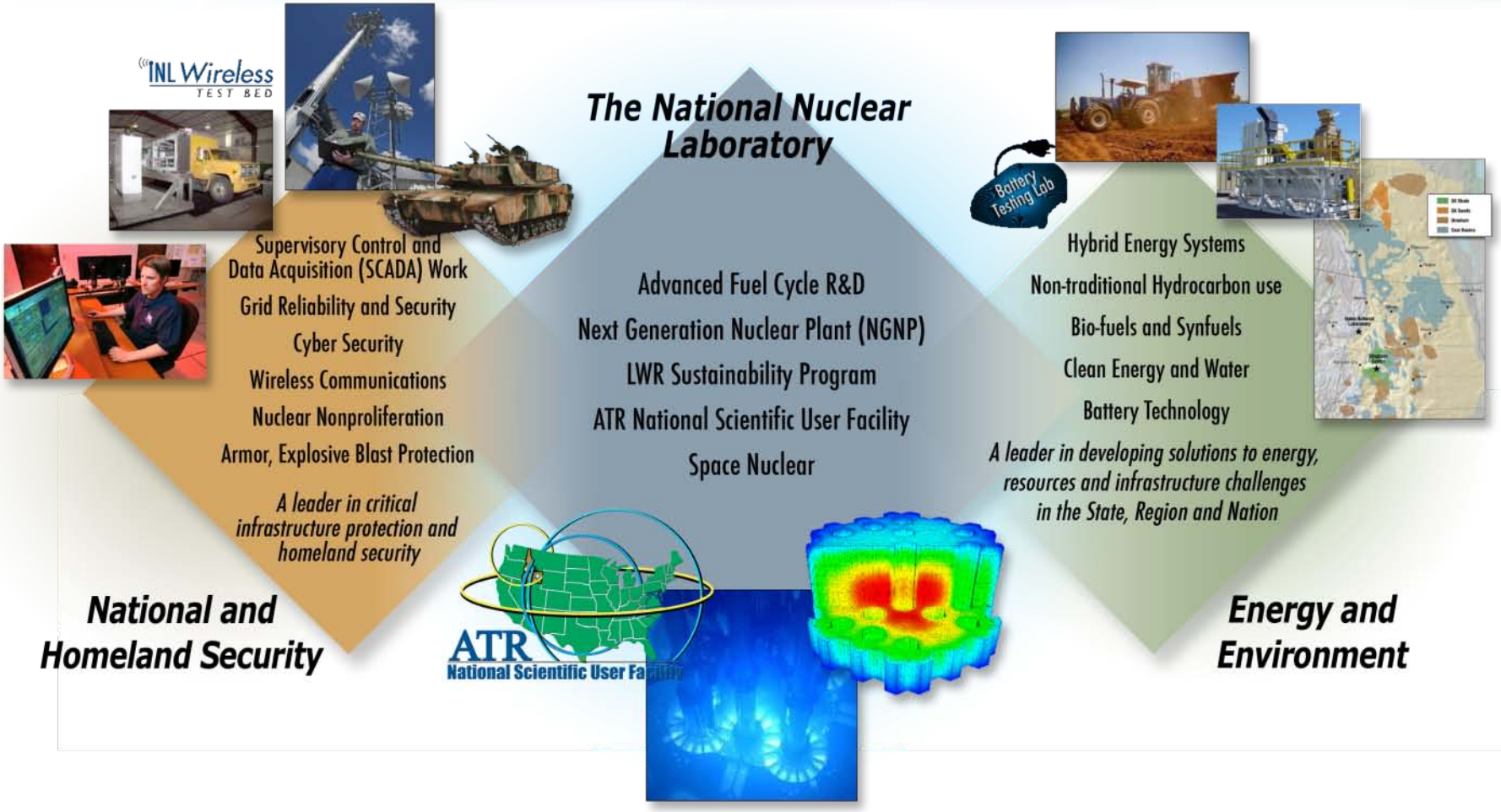
www.inl.gov

Idaho National Laboratory

Idaho National Laboratory — Identity

Research – Development – Demonstration — Deployment

Research Programs of National Importance

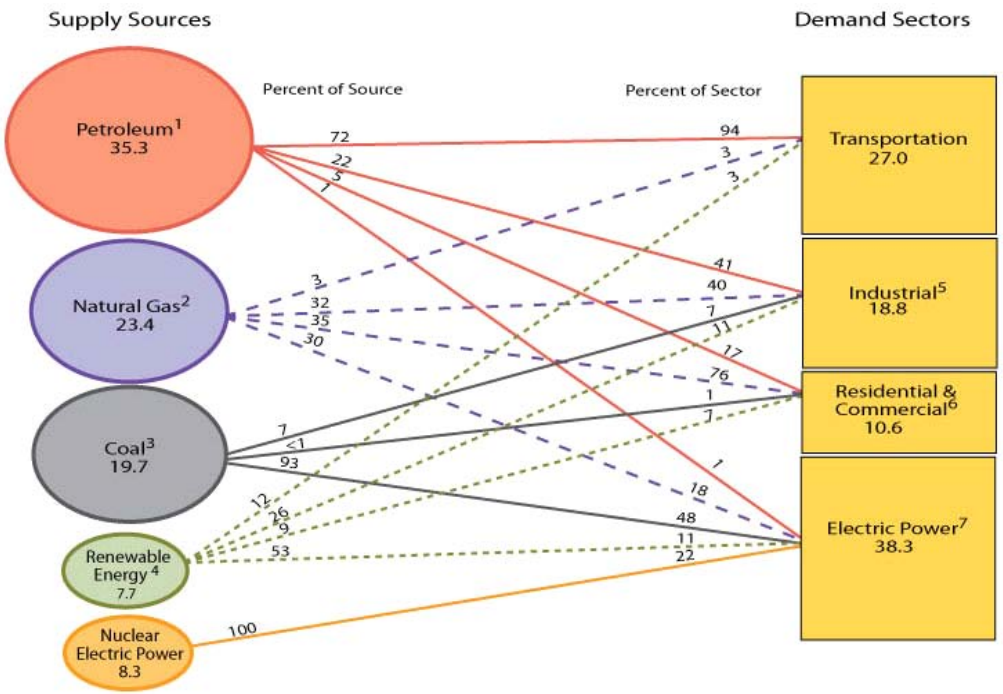


Delivering technologies that benefit our communities, state, region, country and the world

Energy Production and Consumption in U.S. – the Potential Market

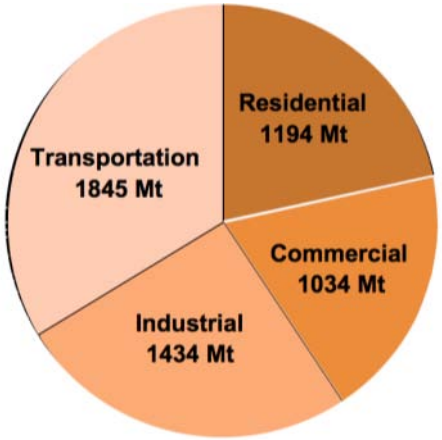
U.S. Primary Energy Flow by Source and Sector, 2009

(Quad -- Quadrillion (1×10^{15}) Btu)



U.S. Greenhouse Gas Emissions by Sector, 2009

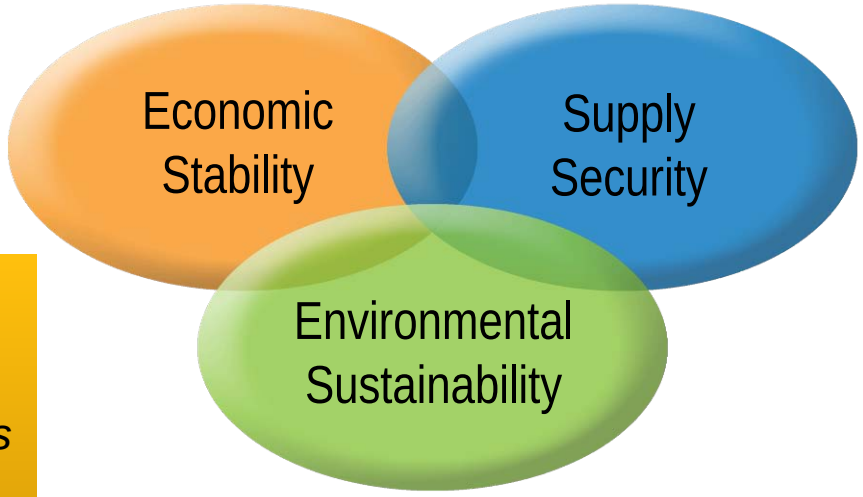
(Million metric tons, CO_2 equivalent AEO 2010, May 2010)



5507 Mt Total

U.S. Industry responsible for 26% of U.S. carbon footprint

Attaining Energy Security

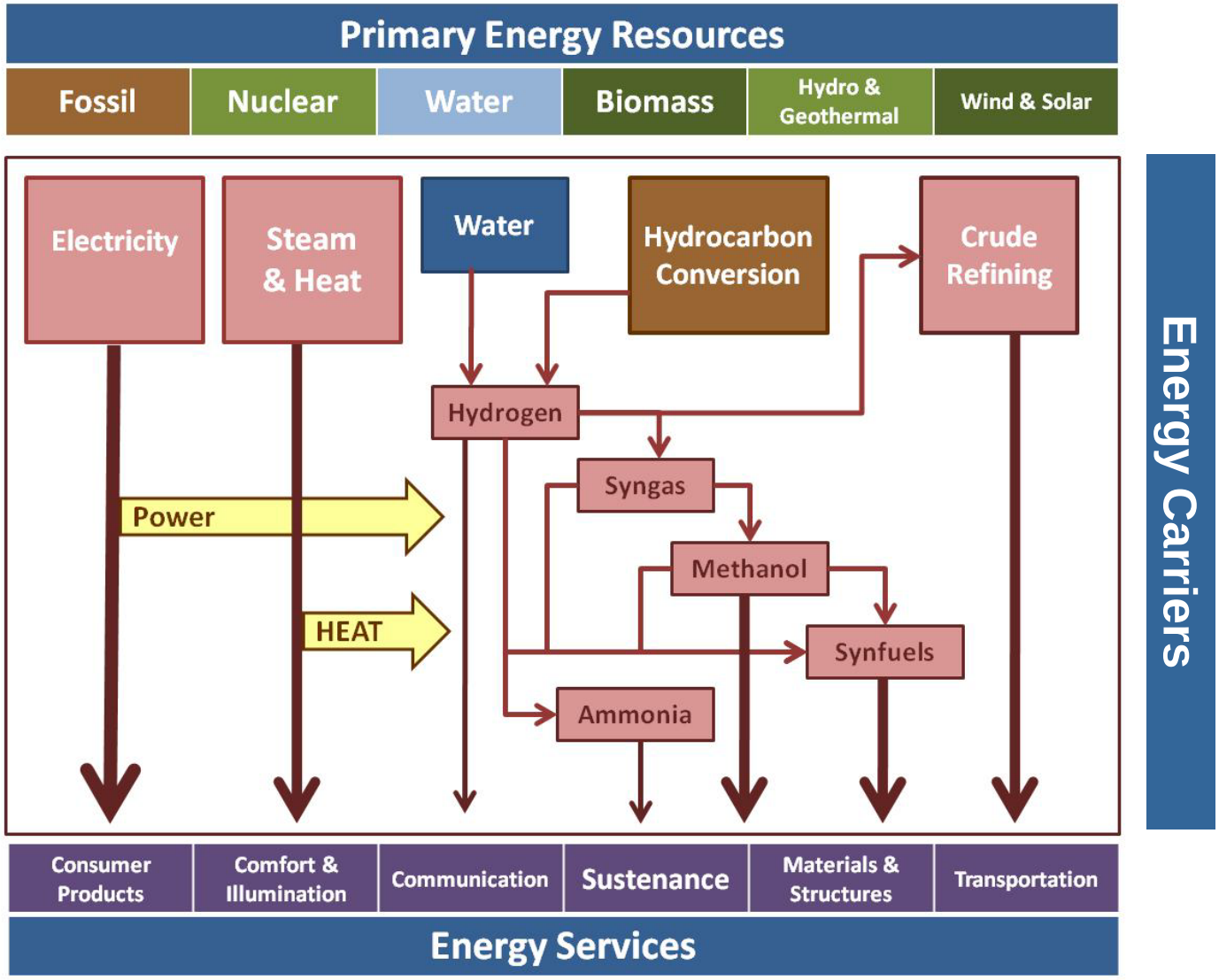


- *Energy cost affordability and stability*
- *Least external costs*
- *Domestic job creation and maintenance*
- *Balance foreign trade, raise tax revenues*

- *Maximize available work from renewable wind, solar, geothermal*
- *Stabilize climate*
- *Reduce air and water pollutant discharges*
- *Water resource conservation*

- *Resource security (availability and accessibility)*
- *Reduce foreign dependence*
- *Maximize benefit of both fossil fuels and biomass energy crops*
- *Conservation of energy resources*

Hybrid Energy : Evolution to a new energy infrastructure

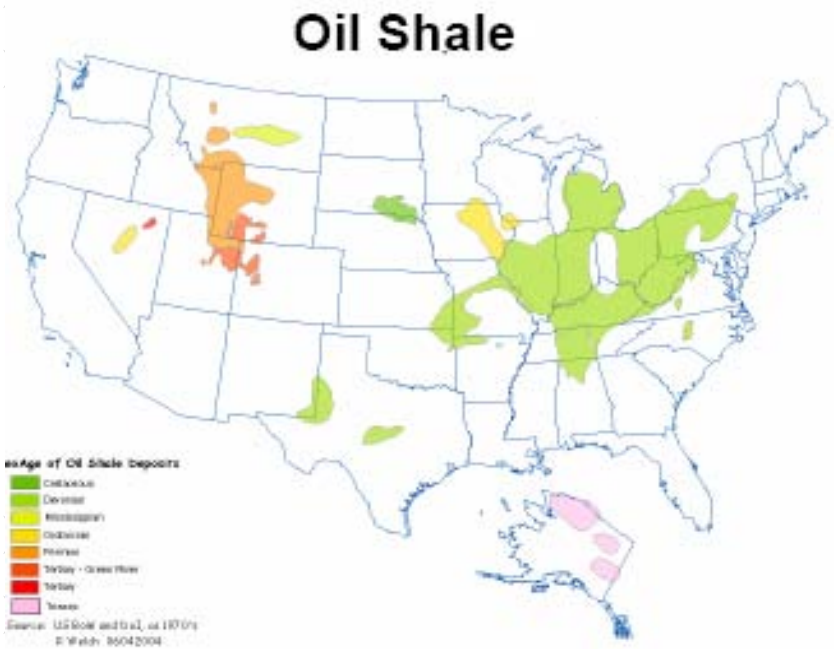


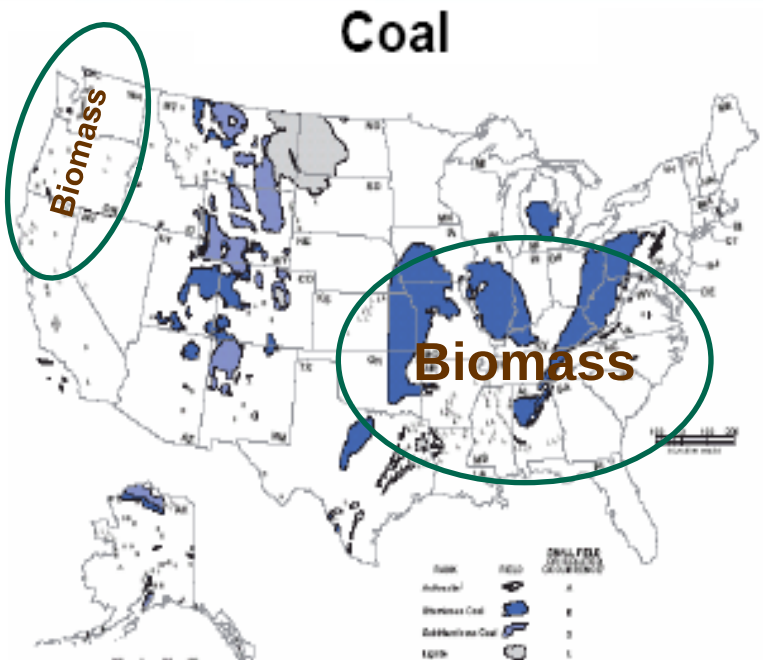
Background

– what, why, where, when, and how

BOE – Barrels of Oil Equivalent

Technical-Economical Studies





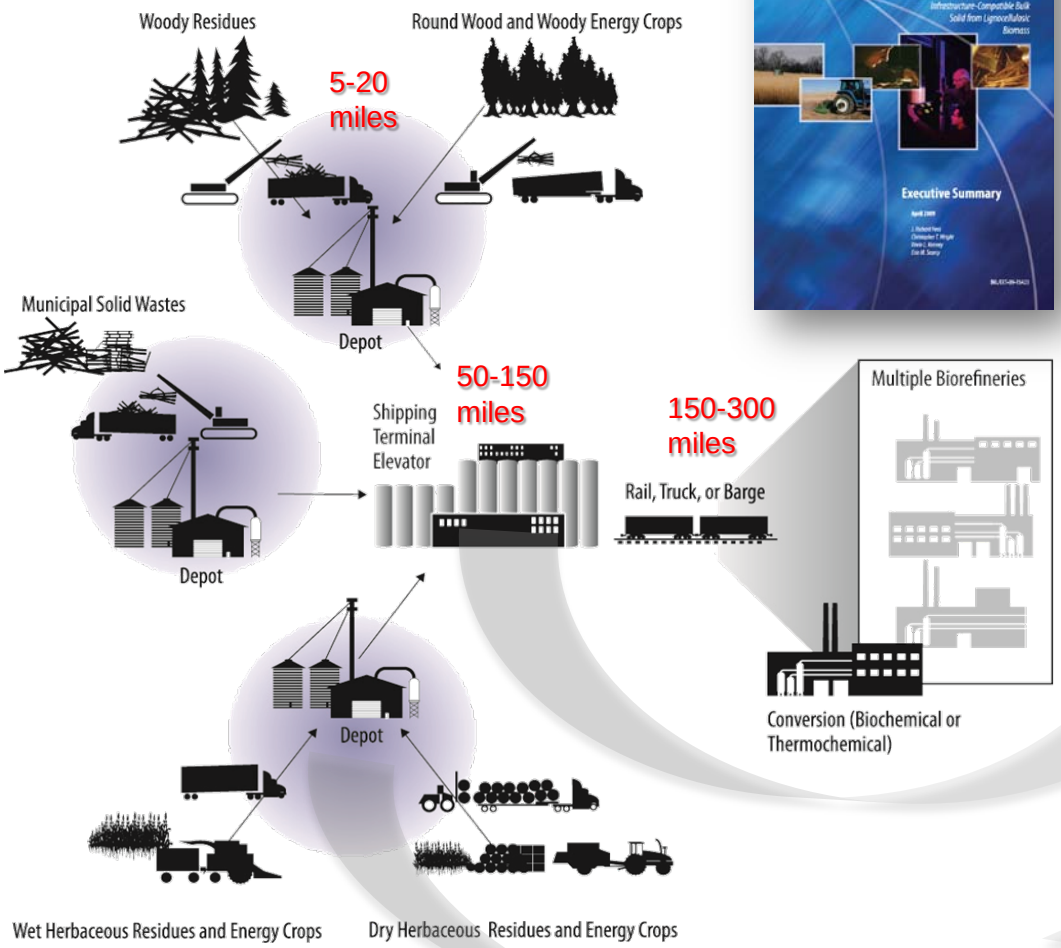
~2 Trillion BOE

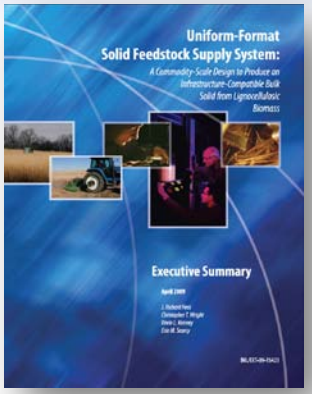
~800 Billion BOE Coal
(50% conversion efficiency)

~1 Billion BOE Fuels
(per year possible)

7.3 billion barrels per year current U.S. demand

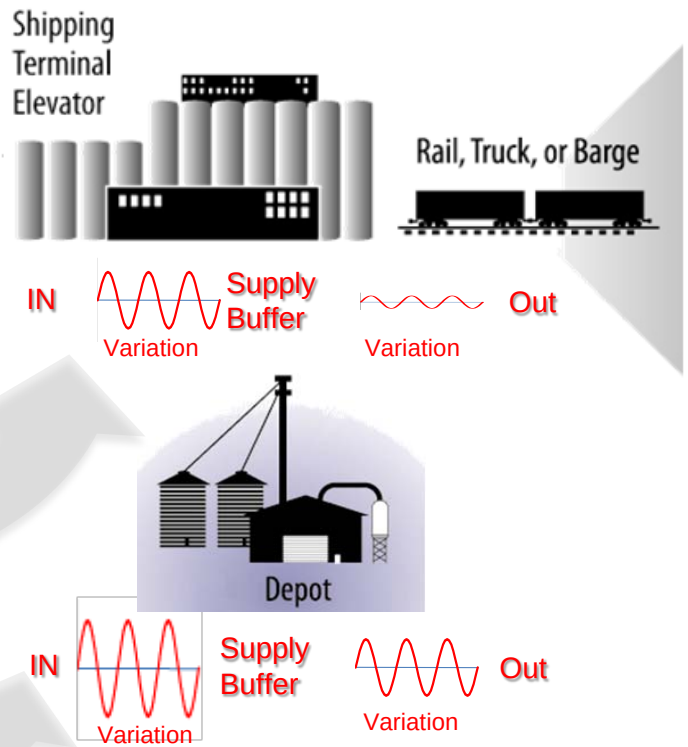
Addressing Logistics and Commodity Considerations



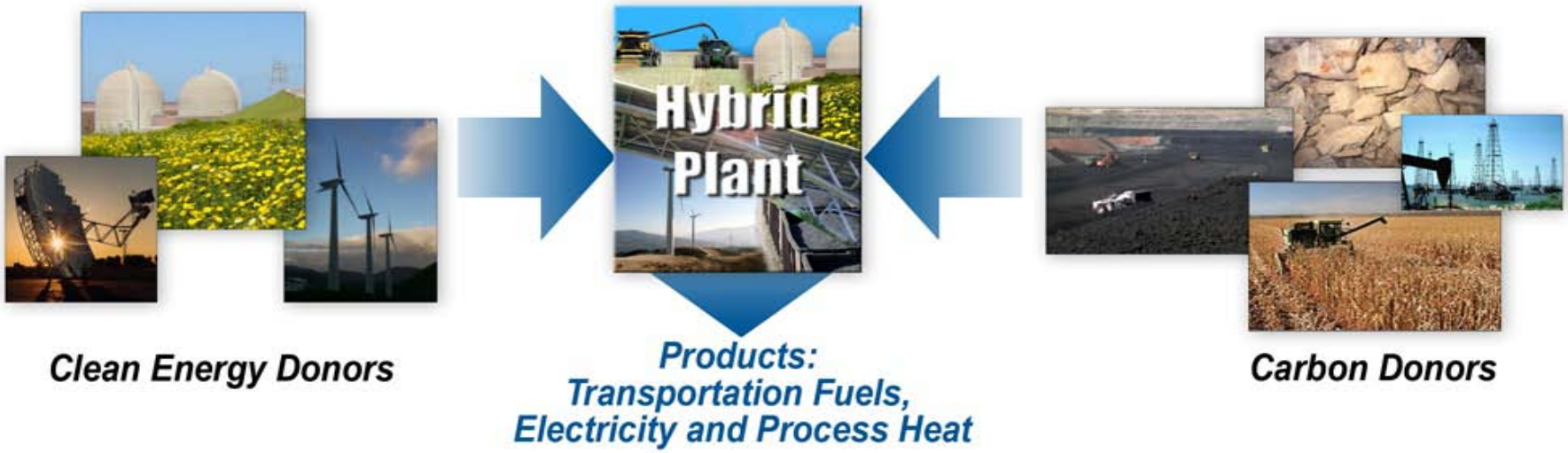


Commodity Attributes:

- Standardized Material/Quality
- National Market
- Biomass Exchange Market



What is a Hybrid Energy System?



- **Tightly coupled systems that exploit complementary characteristics of various energy processes and inputs to produce multiple energy products with life-cycle attributes that help achieve national energy security objectives**
  - Carbon and energy resource considered separately
  - Integration and multi-product approach creates efficiency and flexibility
- **Benefits include:**
  - Greenhouse gas and other air pollutant emissions reduction (e.g., particulate, NOx, SOx, Hg)
  - Optimal use of carbon / non-carbon energy resources
  - Energy production efficiency, adaptability and reliability
  - Greater system stability while integrating intermittent sources
  - Flexibility in accommodating technology change & product demand change
  - Domestic resource & production based (Energy Resiliency)

Co-Gen? Hybrid? What's the Difference?

Generally ……

Single Input / Multiple Output
Loosely Coupled

Multiple Input / Multiple Output
Tightly Coupled

Process Heat Synergies Provide Thermodynamic Efficiencies

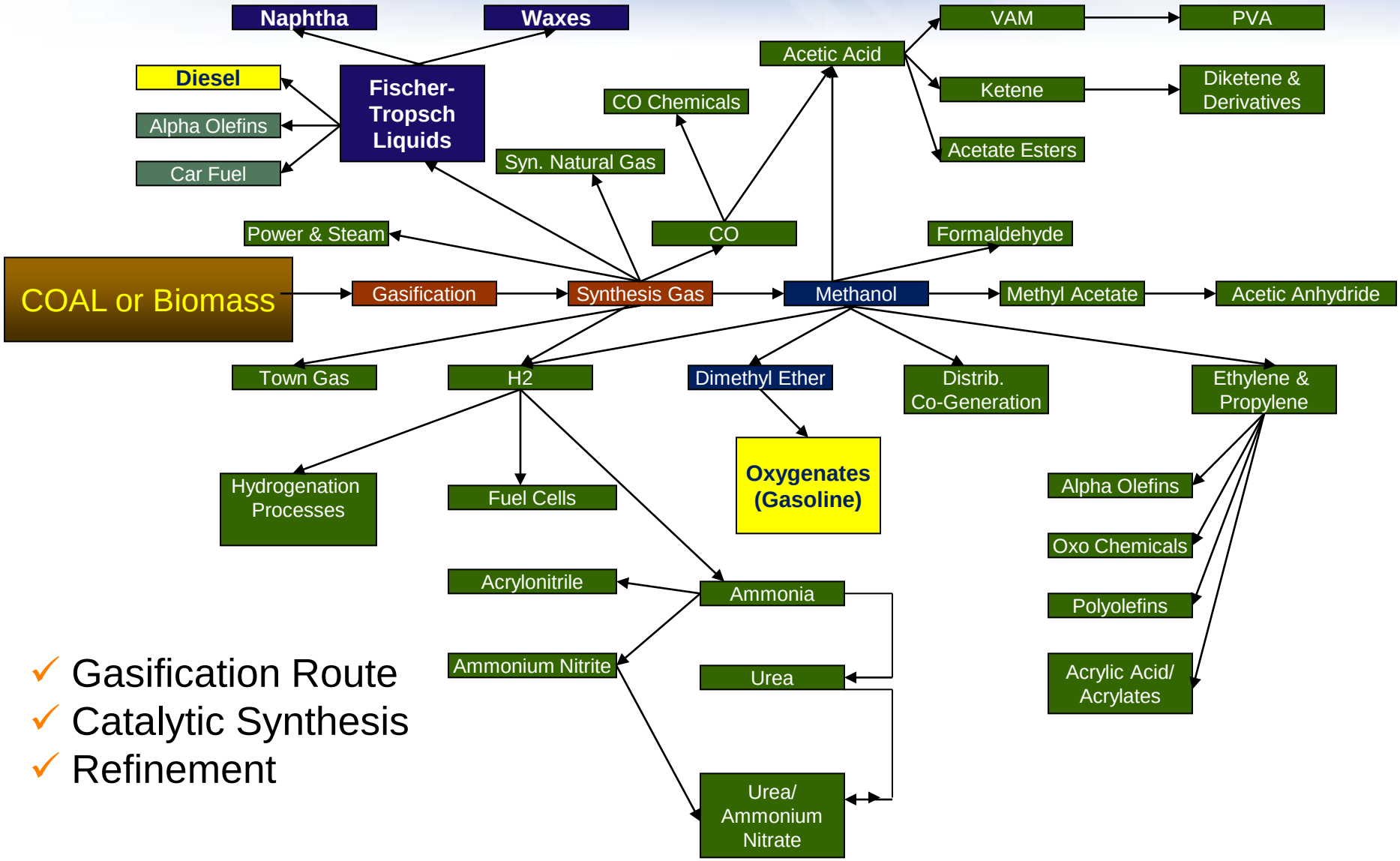
Reactor as "Heat Machine" (Low-Order Coupling)

Feedstock, Process & System Optimization Flexibility Creates Capacity Factor Improvements

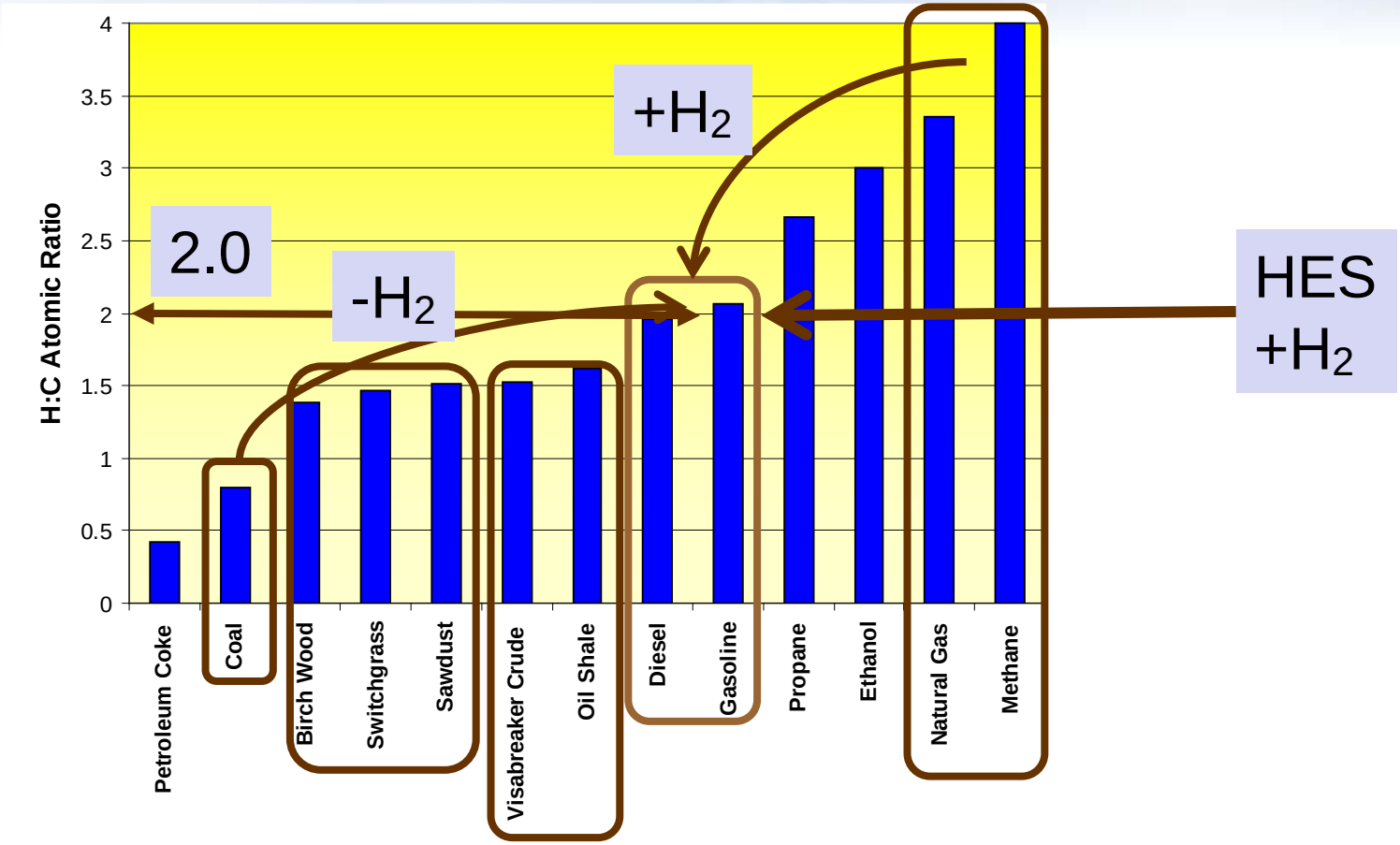
Integrated Energy System (High-Order Coupling)

Co-Generation

Hybrid Systems



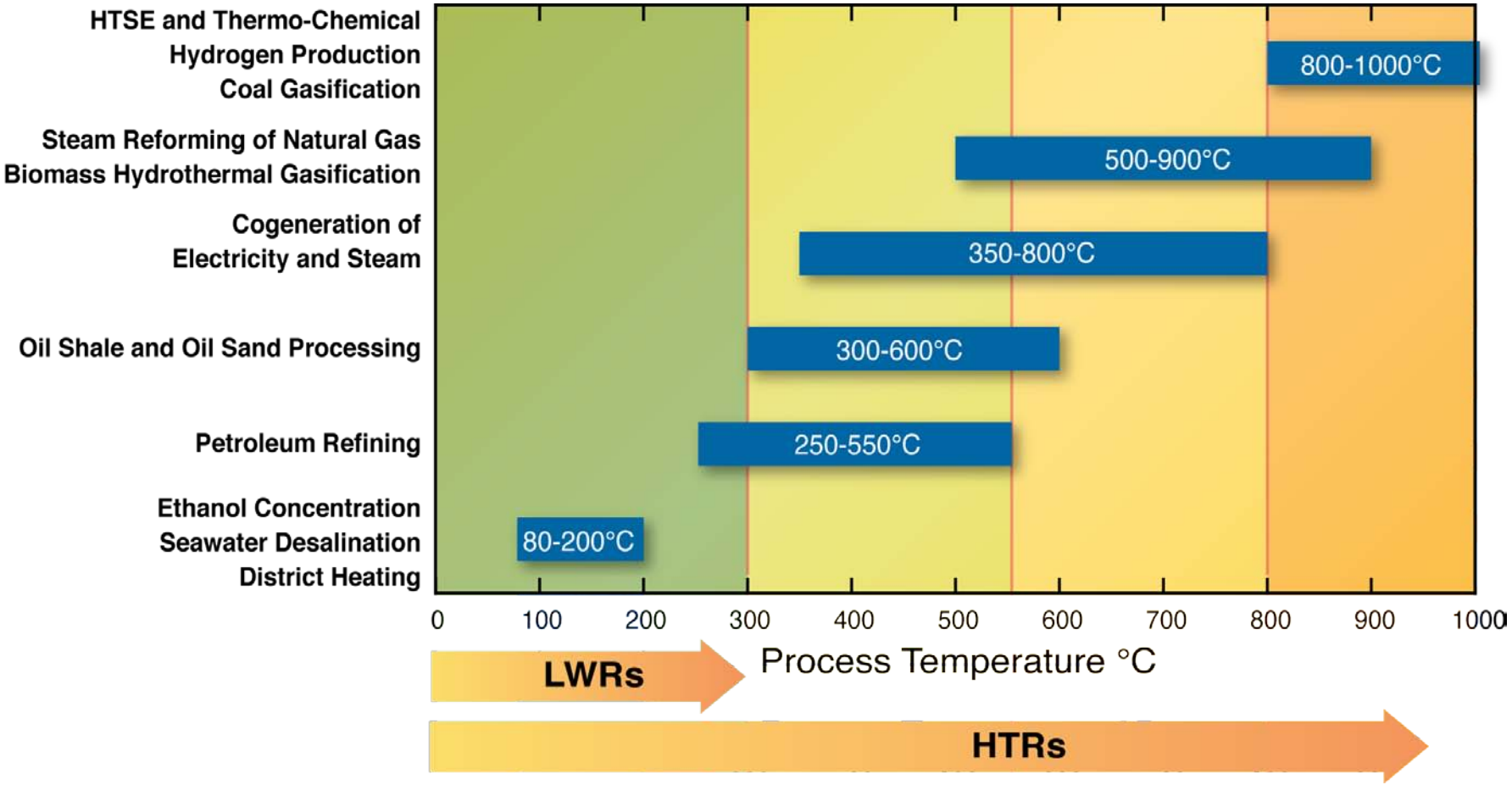
- ✓ Gasification Route
- ✓ Catalytic Synthesis
- ✓ Refinement



Significant hydrogen is needed to upgrade resources. Hydrogen is currently produced through carbon using chemical or sensible heat:

- ✓ $CH_4 + H_20 + ½ O_2 = CO_2 + 3H_2$ **Steam Reforming**
- ✓ $CO + H_20 = CO_2 + H_2$ **Shift Reactor**

Beyond Electricity – Applications of HTGRs



High Temperature Reactors can provide energy production that supports the spectrum of industrial applications including the petrochemical and petroleum industries

Is there an industrial role for small modular nuclear reactors?

General Opportunities

- *Electrical and heat applications*
- *Distributed applications*
- *Hybrid energy systems*
- *Energy independence*

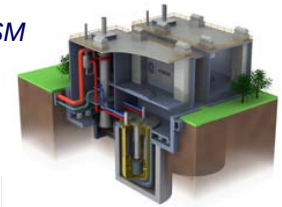
Examples of Emerging Designs

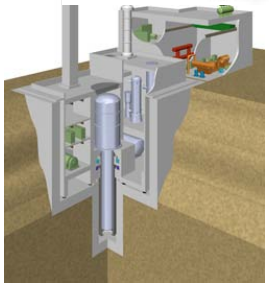
Developer	*Coolant / ROT (°C)*	*Thermal / Electrical*
NuScale	LWR / ~320	160 MWt / 45 MWe
B&W mPower	PWR / ~330	400 MWt / 125 MWe
GE-H PRISM	Liquid Sodium / ~500	840 MWt / 311 MWe
Toshiba 4S	Liquid Metal / ~510	30 MWt / 10 MWe
Pebble Bed	He gas / ~750 – 950	400 MWt / 165 MWe

Technical Advantages

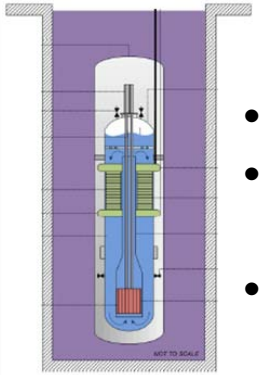
- *Scalable / Right sizable*
- *Modular / Replaceable*
- *Simple / Safe / Sealed*
- *Relatively high outlet temperature (ROT)*
- *Reduce GHG emissions*

PRISM





Toshiba 4S

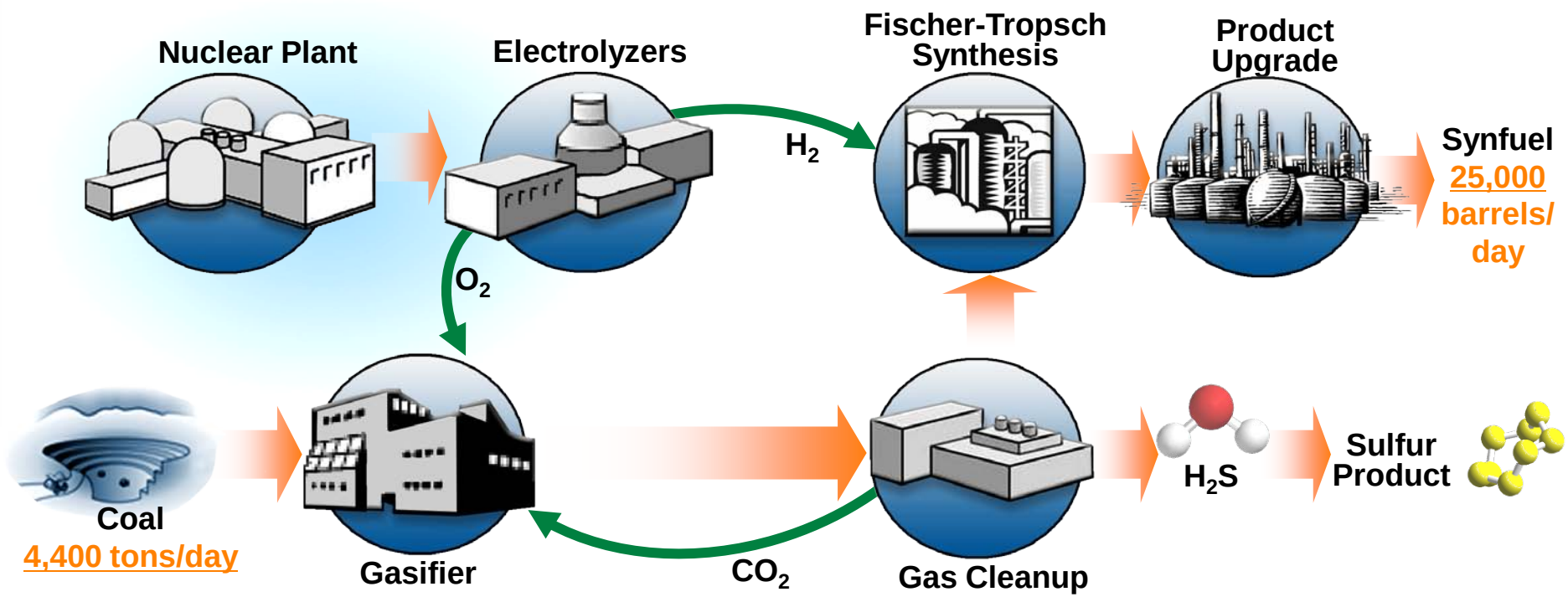


NuScale

Economic Advantages

- *Levelized capital investment*
- *Maximum capacity factor for coupled energy processes*
- *Fossil and biomass energy product increase*
- *Complementary with intermittent wind and solar*

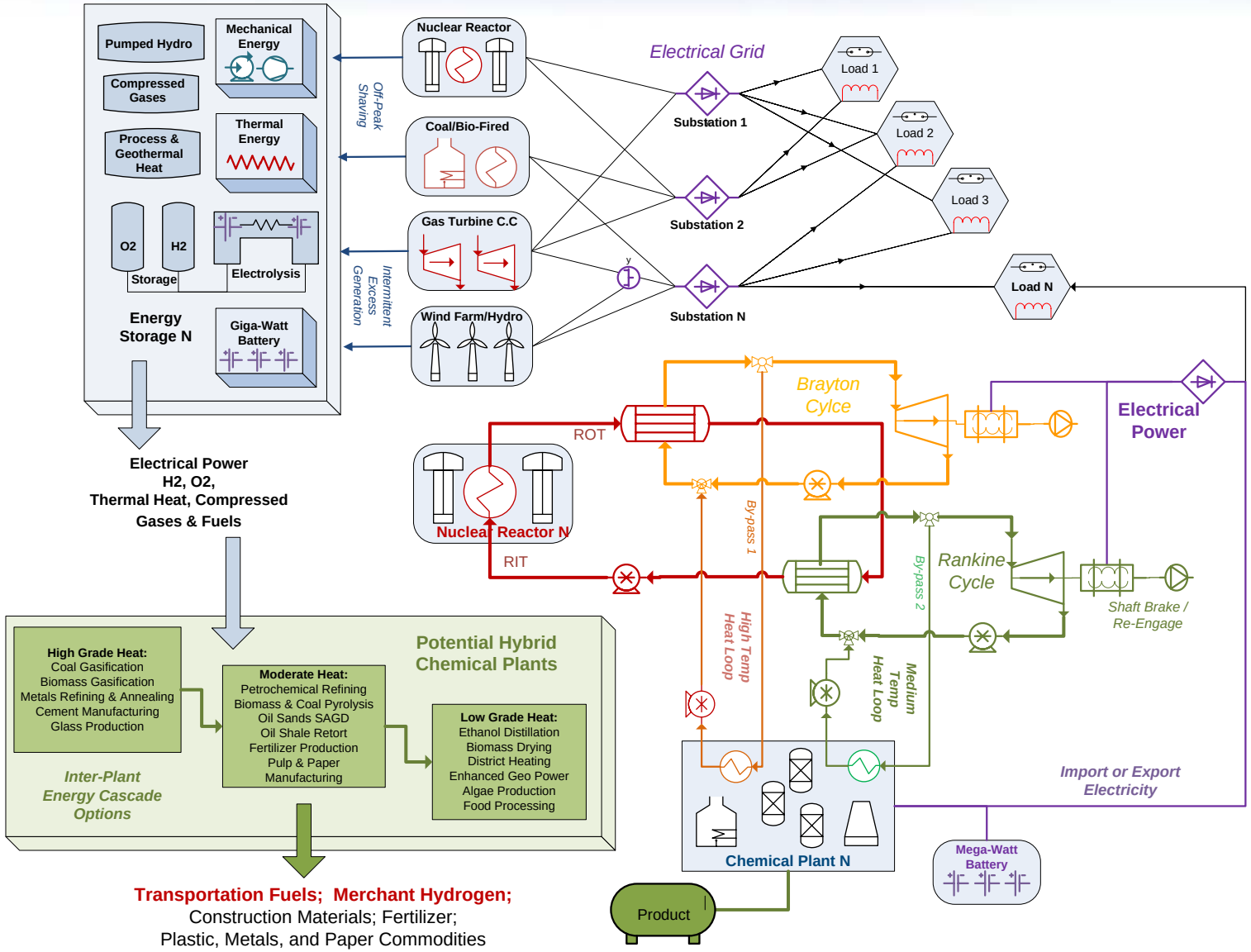
- **Hybrid Energy Systems**
- **National Security Ramifications**



- ✓ Hybrid systems uses 70% less coal
- ✓ Little carbon is converted to CO_2

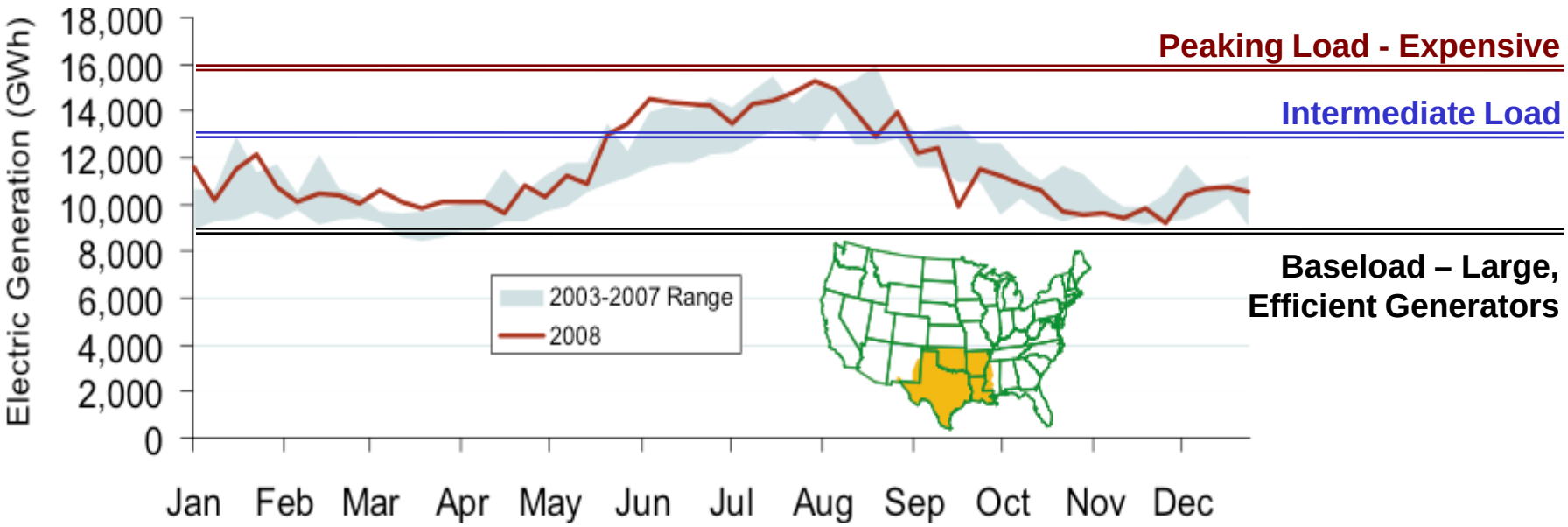
- ✓ Small amount of CO_2 is recycled to gasifier
- ✓ Effectively no CO_2 emissions

System-Wide Nuclear Hybrids Integration with the Grid



Nuclear Hybrids Enhance Renewables: Stability and Security for the Grid

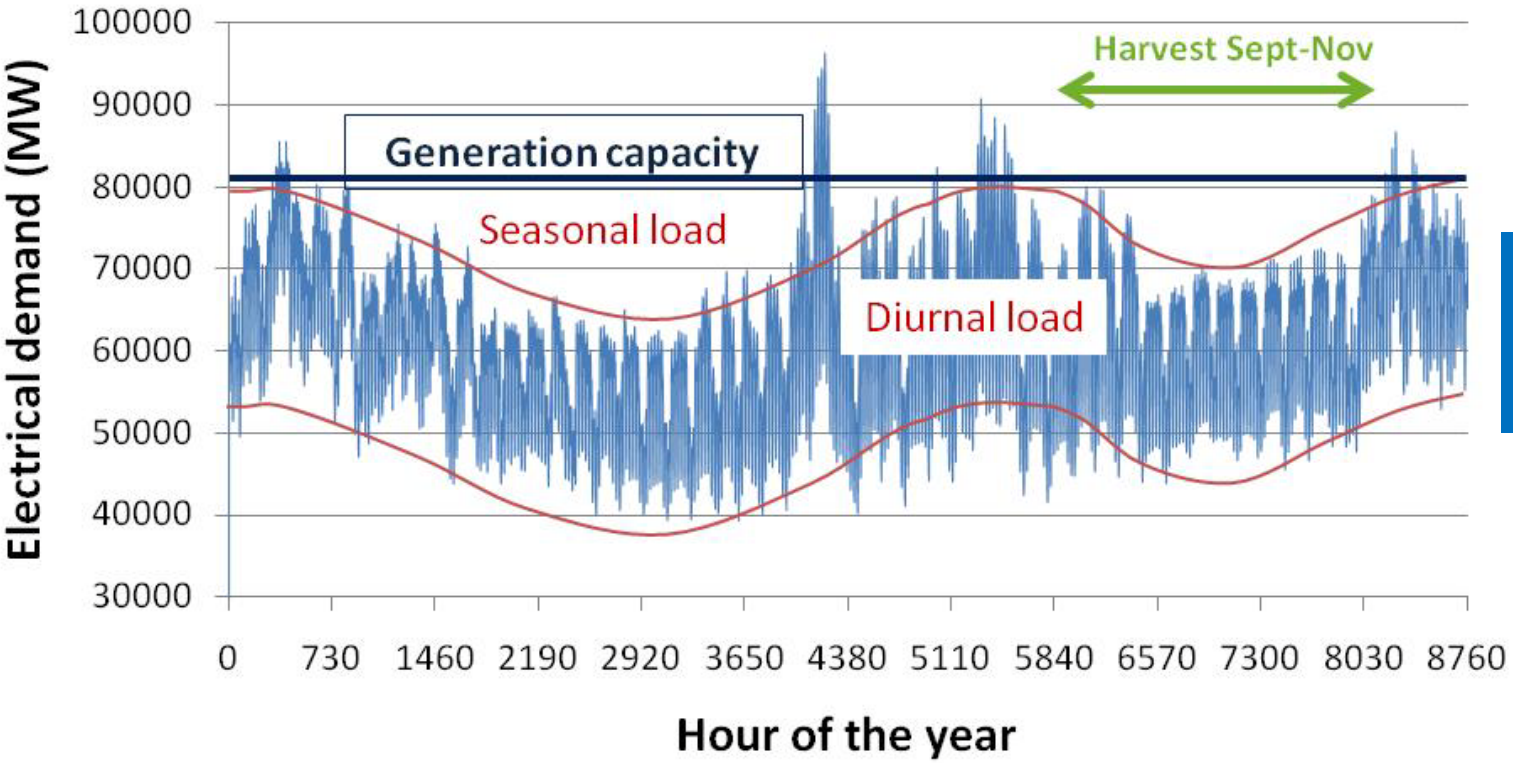
Intermittent Renewables Constrained By Present Transmission System Architecture



Electrical Generation – Present Approach

Source: Market Oversight @FERC.gov

- **Hybrid Energy Systems**
- **National Security Ramifications**



- ✓ Diurnal load available for hydrogen production

Why the Idaho National Lab?

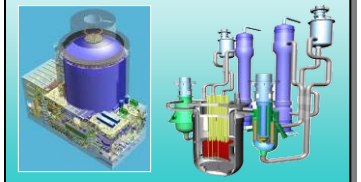
- **INL leadership in energy systems demonstration and several platforms**
- **Integrating principle for Laboratory programs**

Nuclear Energy Technology

Used Fuel Separations

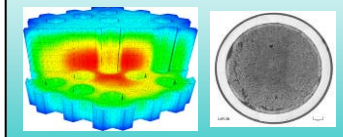
Fuel Cycle Technology

Advanced Reactor Design
Gen-IV Systems
LWR Sustainability



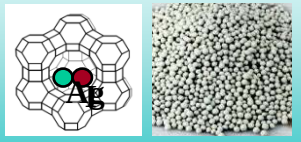
Reactor Systems

Fuel Performance Advanced
Fuel Design & Testing
Materials Performance



Advanced Fuels and Materials

Waste Form Development
& Testing



Radioactive Waste

Licensing Support
Design and Safety Methods

Nuclear Safety

Nuclear Energy Integration

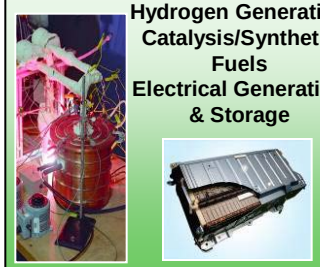
Resource extraction
Feedstock assembly
Thermal treatment

Feedstock Extraction & Processing

Heat exchanger/ heat circulation Heat deposition
Gas & liquids T/H Thermal Design

Energy Transfer

Hydrogen Generation
Catalysis/Synthetic Fuels
Electrical Generation & Storage



Energy Storage

CO2 Separation,
Recycle or Sequestration
Alternative CO2 Uses

Byproduct Management

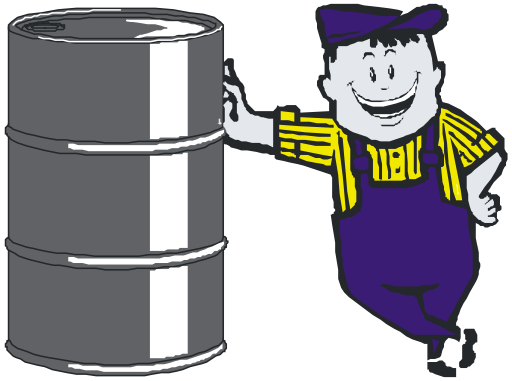
Lifecycle Analyses, Hybrid System Design, Signal Processing & Visualization
Advanced Controls

Systems Analyses, Integration, Monitoring & Control

- Hybrid Energy Systems
- National Security Ramifications

Strategic Petroleum Reserve

Insurance against short-term oil shortages caused by economic disruption and oil supply interdiction



Term Insurance

OR

Strategic Holistic Energy Plan

Long range energy planning for production of domestically derived replacement fuels, and hybrid systems with all energy resources

Whole Life Insurance