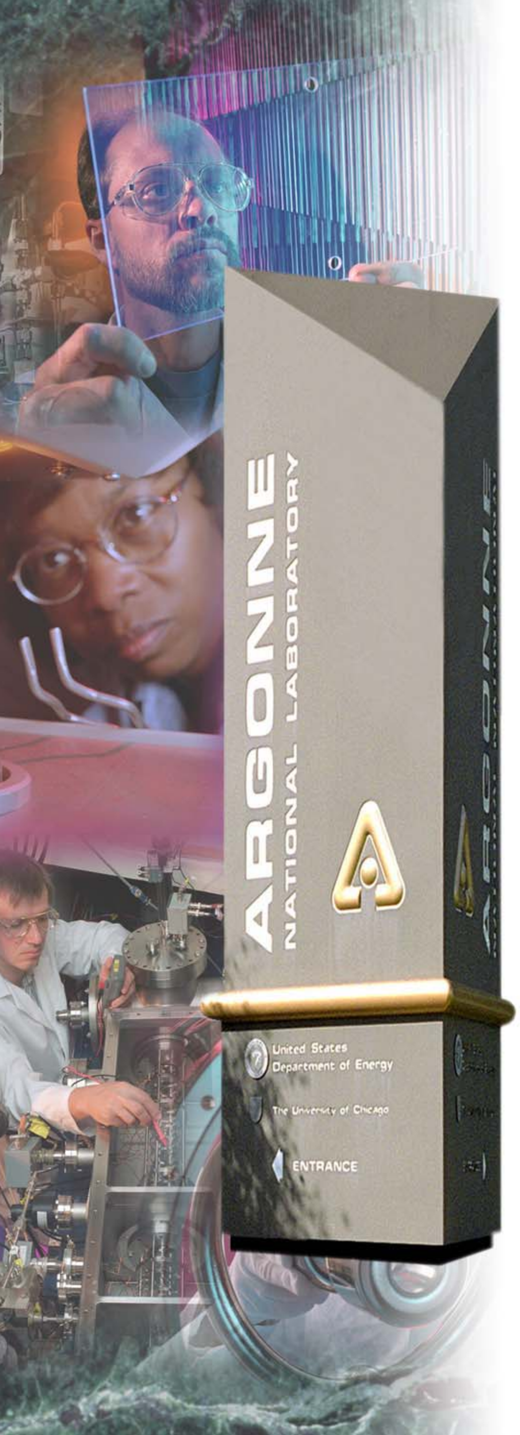

Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Hydrogen Produced with Nuclear Energy

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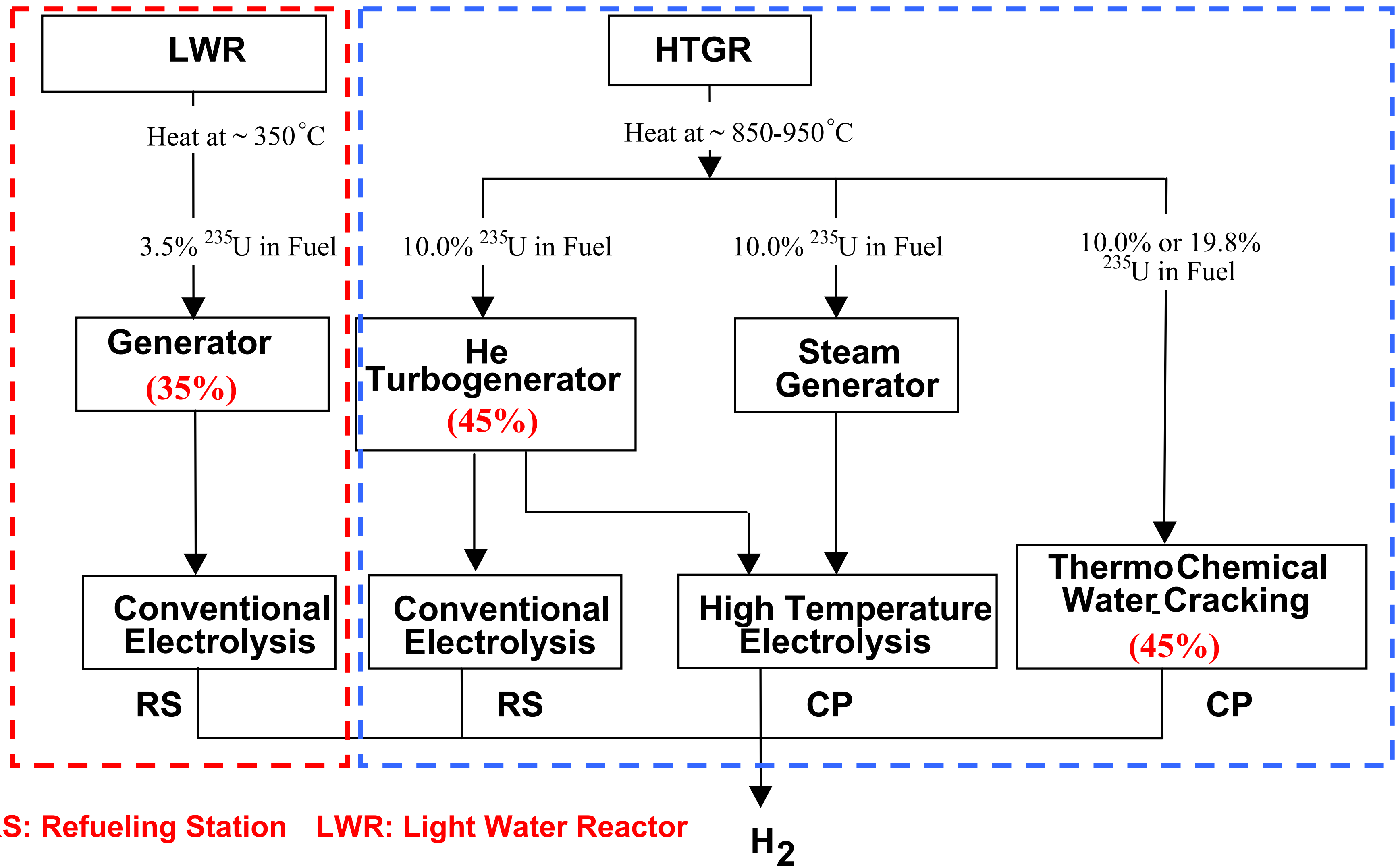
Background

- **Key motivations for seeking alternative sources to meet our energy needs:**
  - Potential shortage of petroleum
  - Potential climate changes by greenhouse gases
  - H_2 can be produced from many sources
- **Nuclear energy could be an important choice**
  - Current H_2 production from steam methane reforming generates emissions and consumes natural gas
  - Nuclear ore is more abundant than fossil fuels
  - Fuel-cell vehicles, undergoing extensive R&D efforts, could use nuclear-based H_2

The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model

- **GREET estimates emissions of greenhouse gases**
  - CO_2, CH_4, and N_2O
  - VOC, CO, and NO_X as optional GHGs
- **GREET estimates emissions of five criteria pollutants**
  - VOC, CO, NO_X, SO_X, and PM_{10}
- **GREET separates energy use into**
  - All energy sources
  - Fossil fuels (petroleum, natural gas, and coal)
  - Petroleum
- **GREET has more than 30 fuel pathway groups, including H_2 fuel pathways**
- **GREET is posted at http://greet.anl.gov and available free of charge; there are >1,200 registered GREET users now**

Four Nuclear H_2 Pathways Were Analyzed



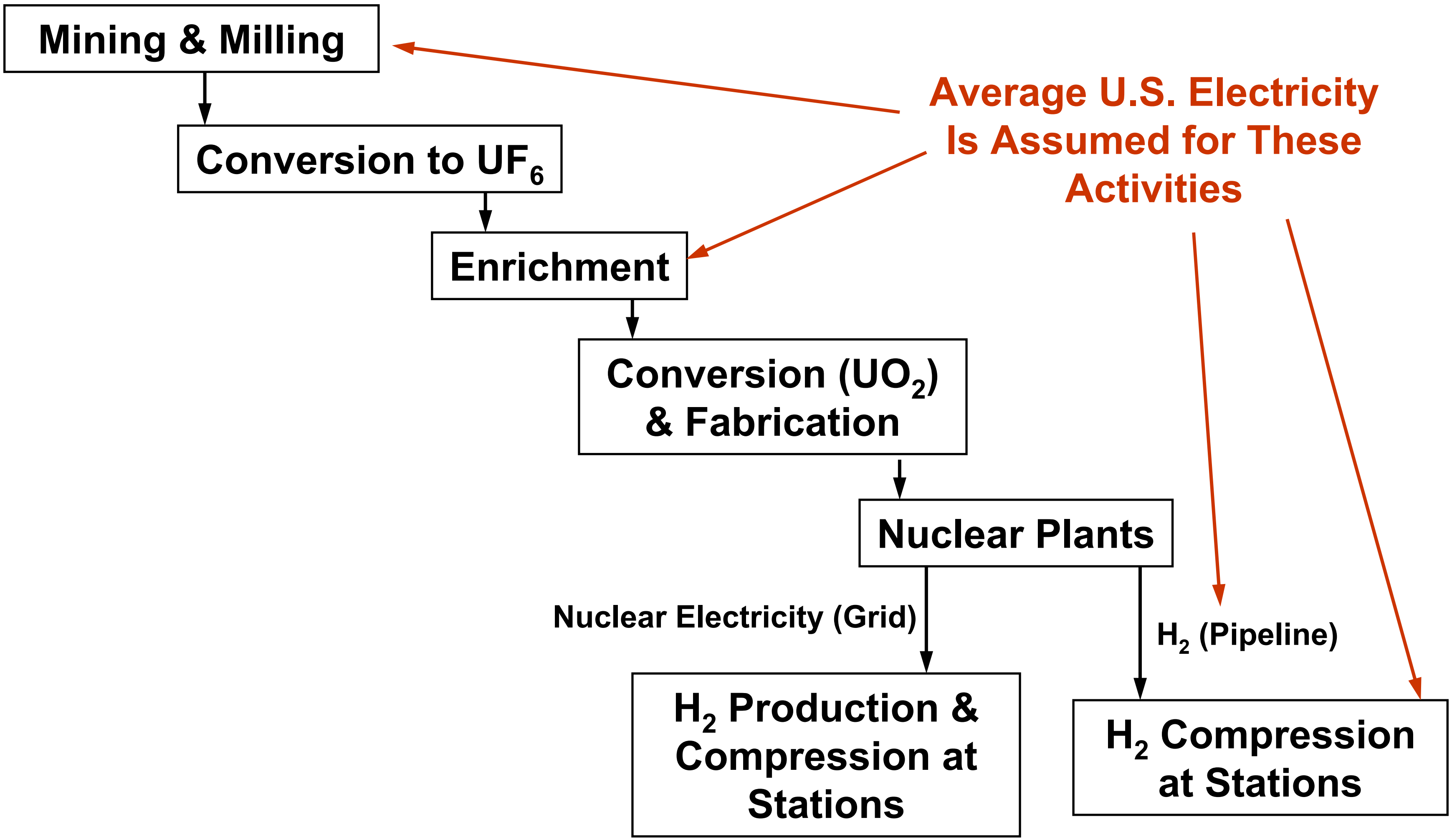
RS: Refueling Station

CP: Central Plant

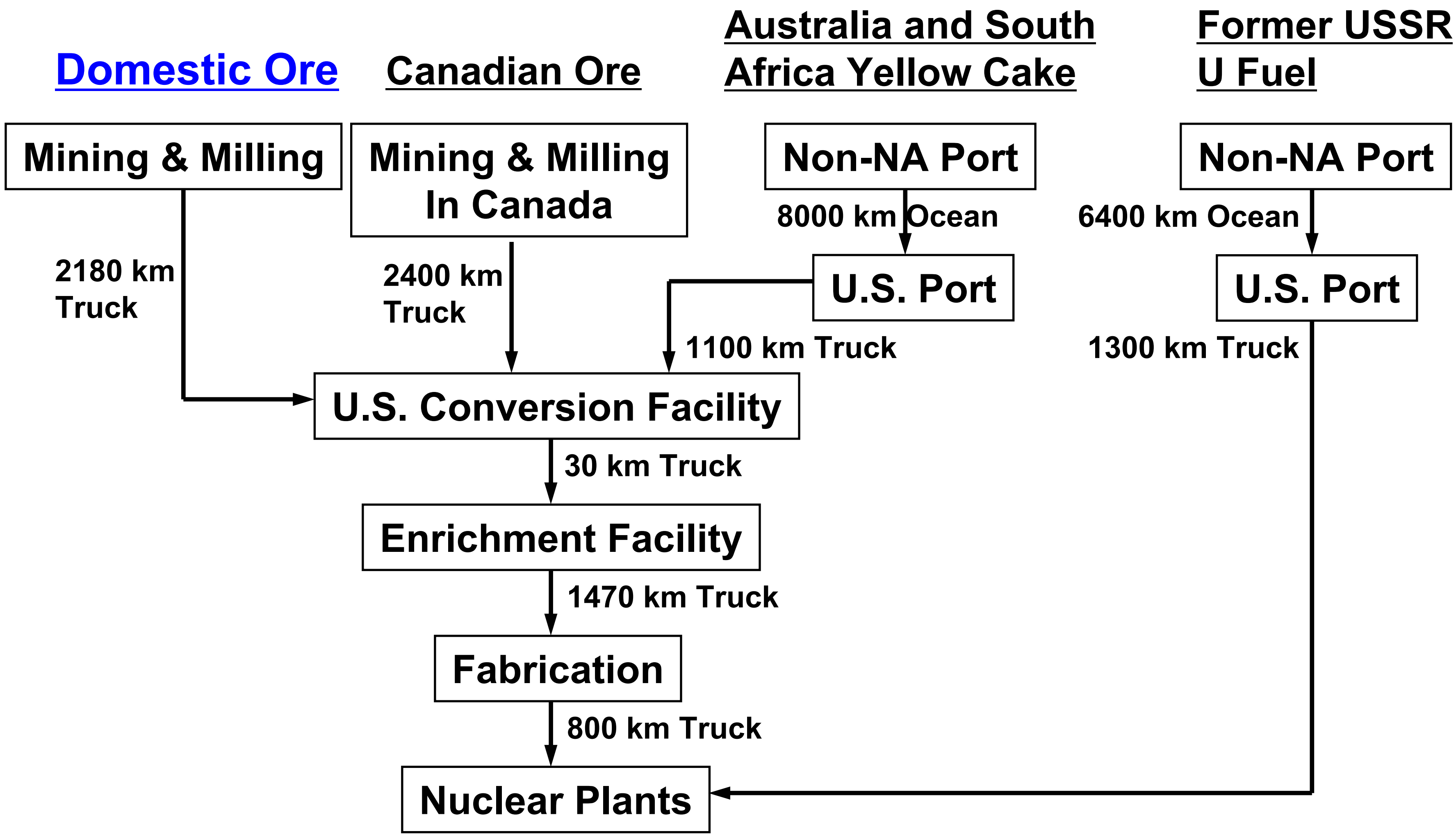
LWR: Light Water Reactor

HTGR: High-Temperature Gas-Cooled Reactor

Nuclear H_2 Pathways Have Several Well-to-Pump Stages



Uranium Can Come From Different Locations



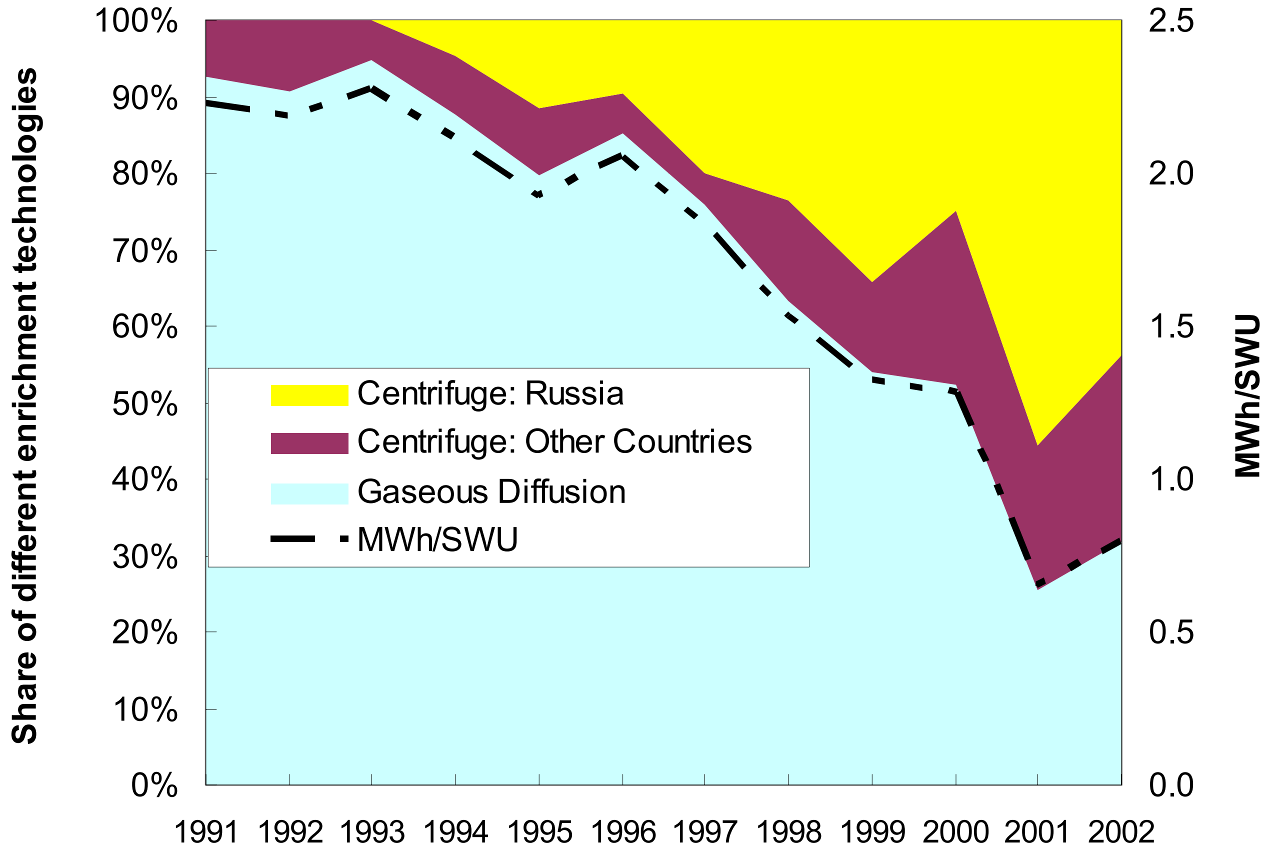
This study simulates the domestic uranium ore supply only.

Project Team Researched Key Input Parameters

- **LWR electricity generation and electrolysis H_2 production**
  - U235 concentration of nuclear fuels: 3.5% (155 kg SWU/kg U235)
  - Station electrolysis efficiency: 71.5%
- **HTGR electricity generation and H_2 production**
  - U235 concentration of nuclear fuels: 10.0% (209 kg SWU/kg U235)
  - U235 concentration of nuclear fuels: 19.8% (229 kg SWU/kg U235)
  - Central plant high-temperature electrolysis efficiency: 80%
  - Station electrolysis efficiency: 71.5%
- **Electricity generation intensity**
  - LWR: 6.9 MWh/g U235 (3.5% U235)
  - HTGR-A: 8.7 MWh/g U235 (10.0% U235)
  - HTGR-B: 8.1 MWh/g U235 (19.8% U235, source-General Atomics)
- **Electricity requirements for uranium fuel enrichment**
  - Gas diffusion process: 2,400 kWh/kg SWU
  - Centrifuge process: 50 kWh/kg SWU

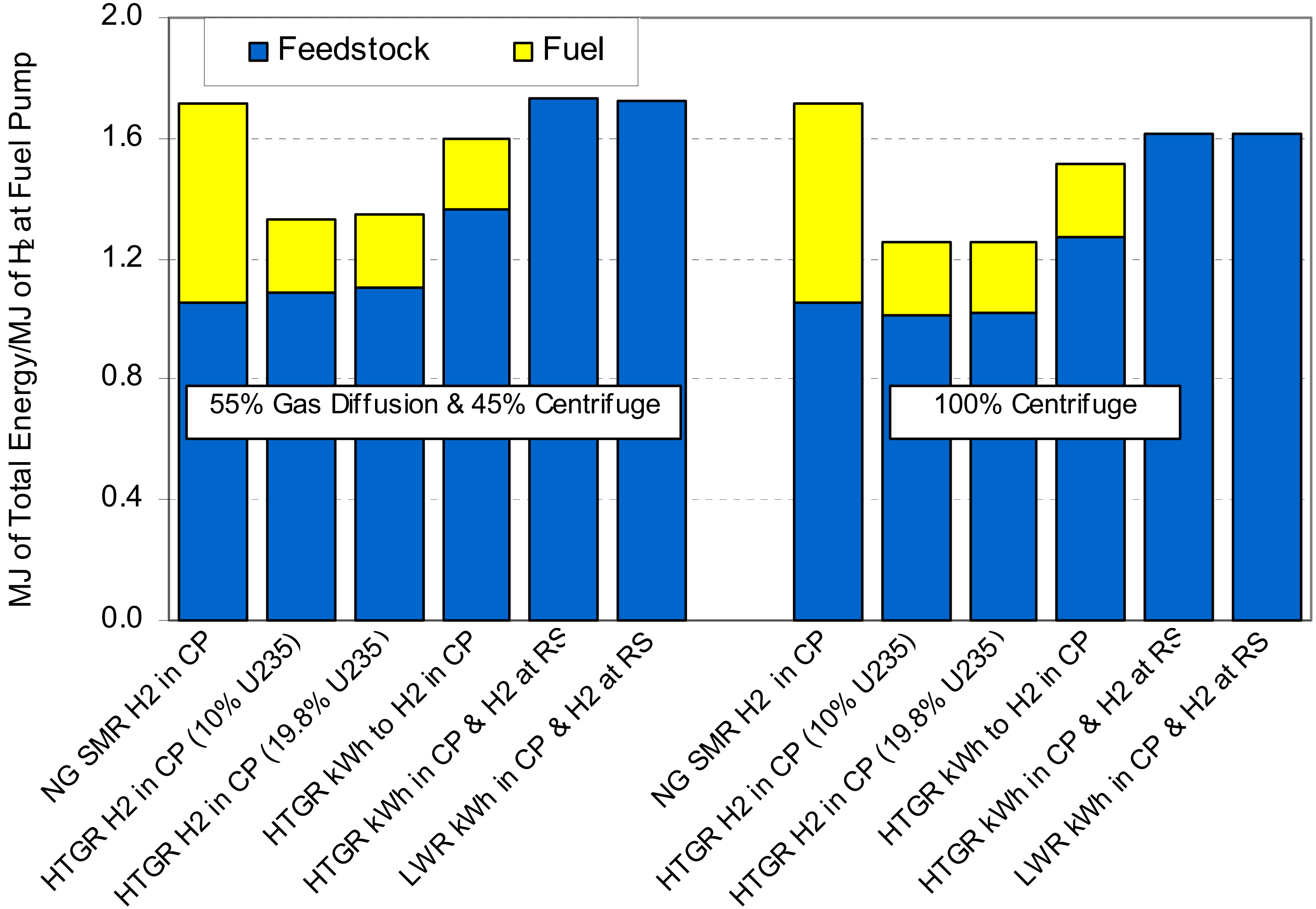
SWU: Separative Work Units

Share of Gaseous Diffusion and Centrifuge Enrichment Technologies

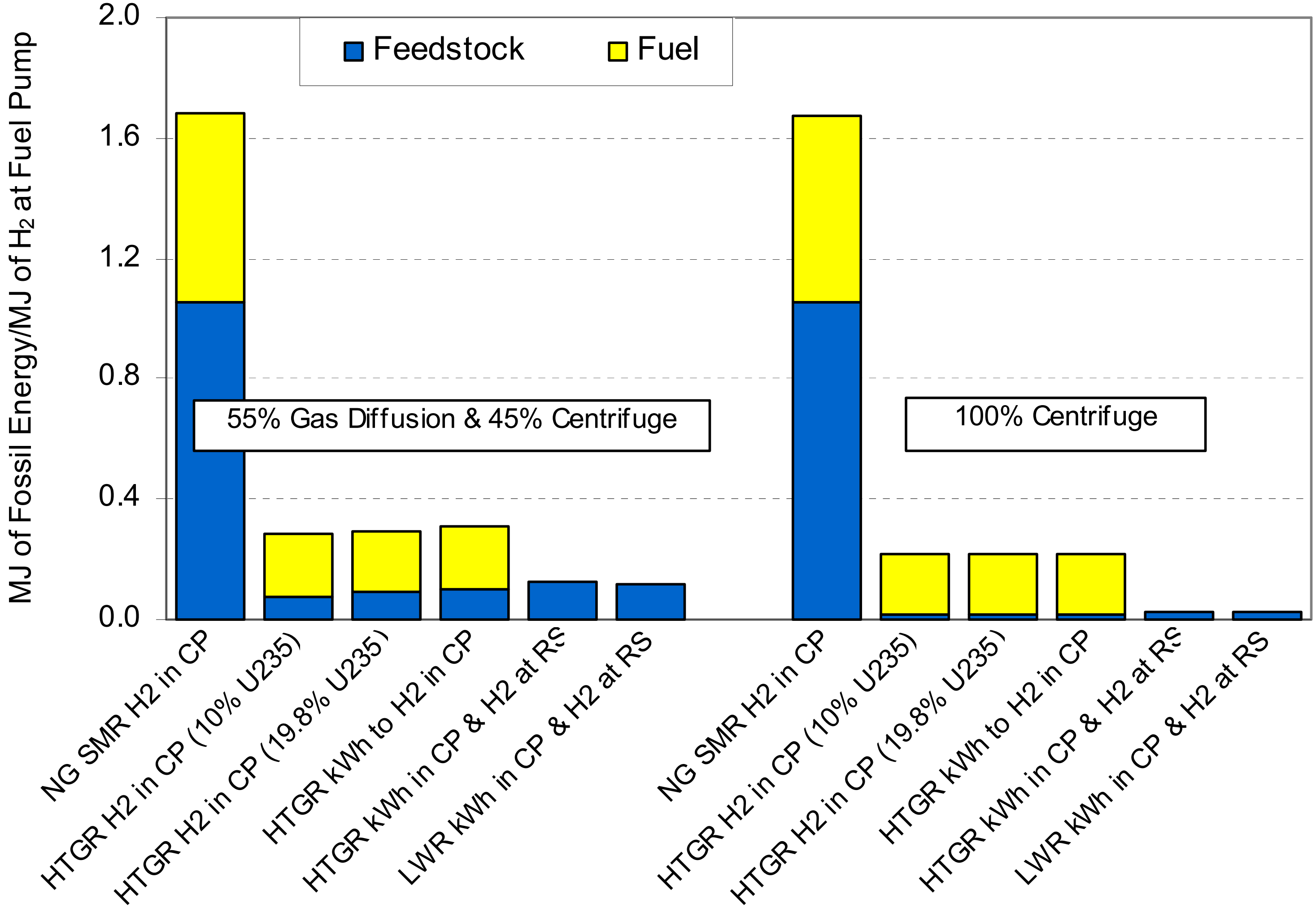


- **The share of gaseous diffusion enrichment decreased significantly during the last decade**
- **Average split between 1996 and 2002:**
  Gaseous diffusion vs. centrifuge =55%: 45%
- **Future trend:**
  Gaseous diffusion vs. centrifuge =0%: 100%

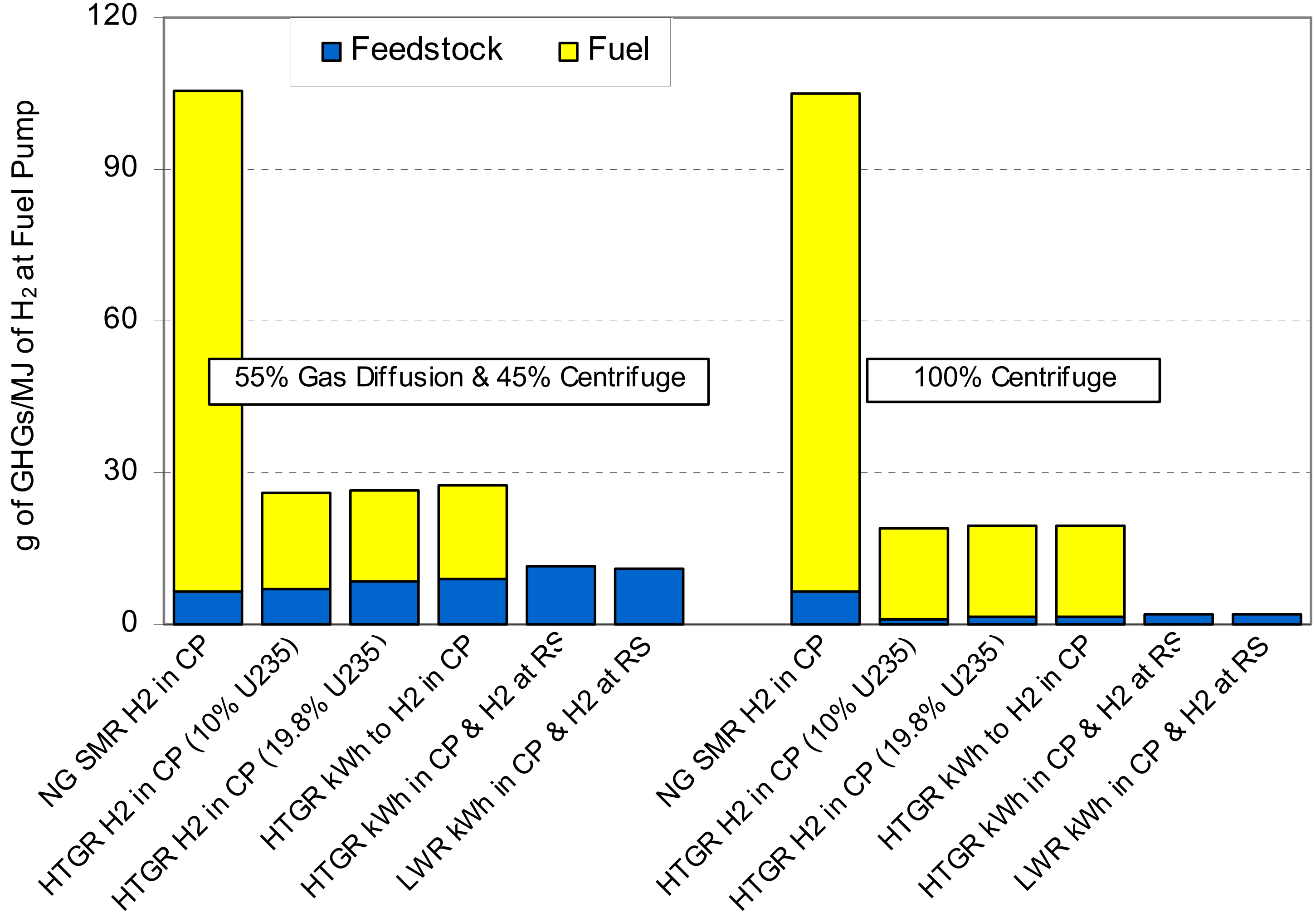
Well-To-Pump Results: Total Energy Use (MJ per MJ of H_2 at Fuel Pump)



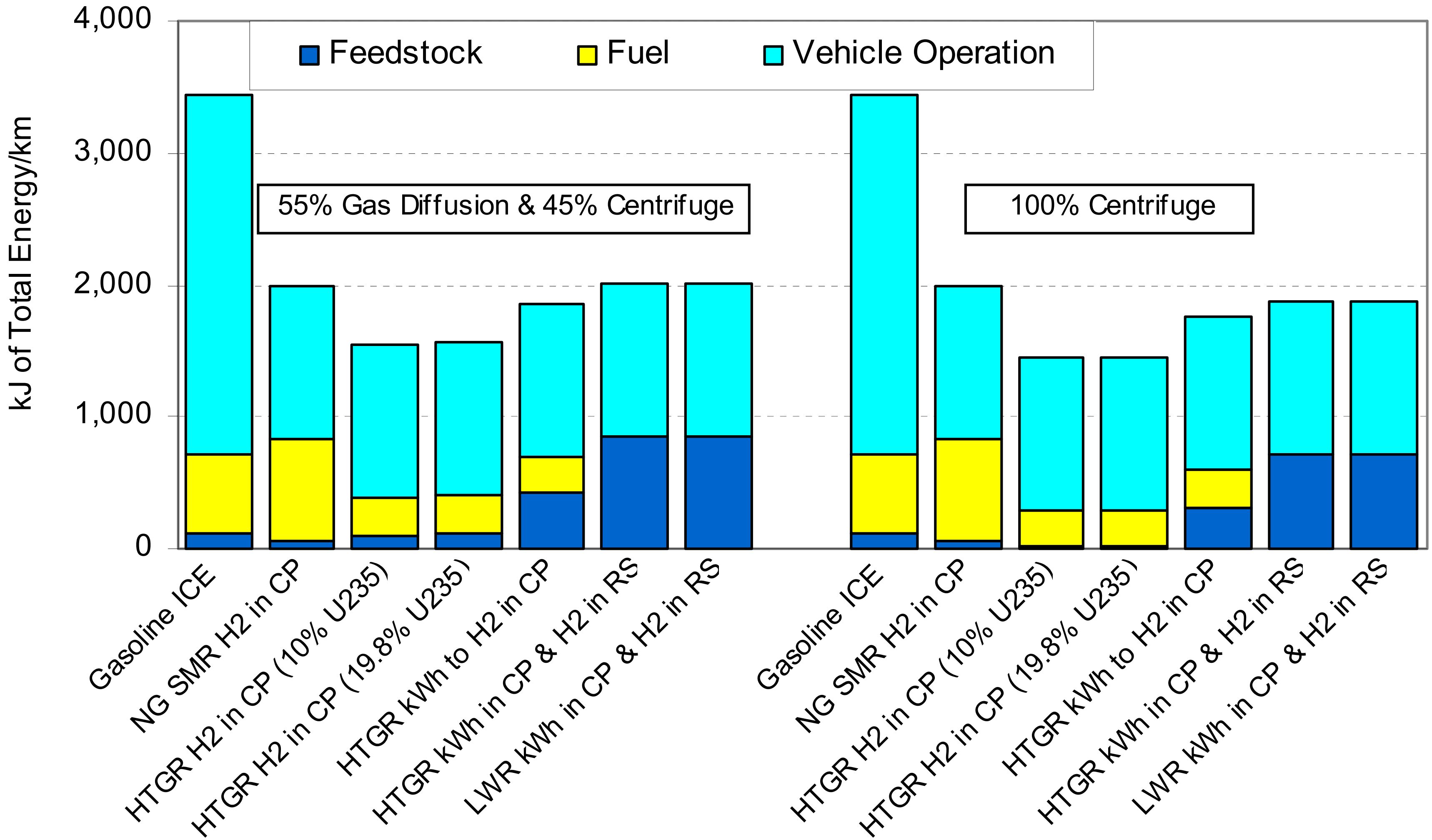
Well-To-Pump Results: Fossil Energy Use (MJ per MJ of H_2 at Fuel Pump)



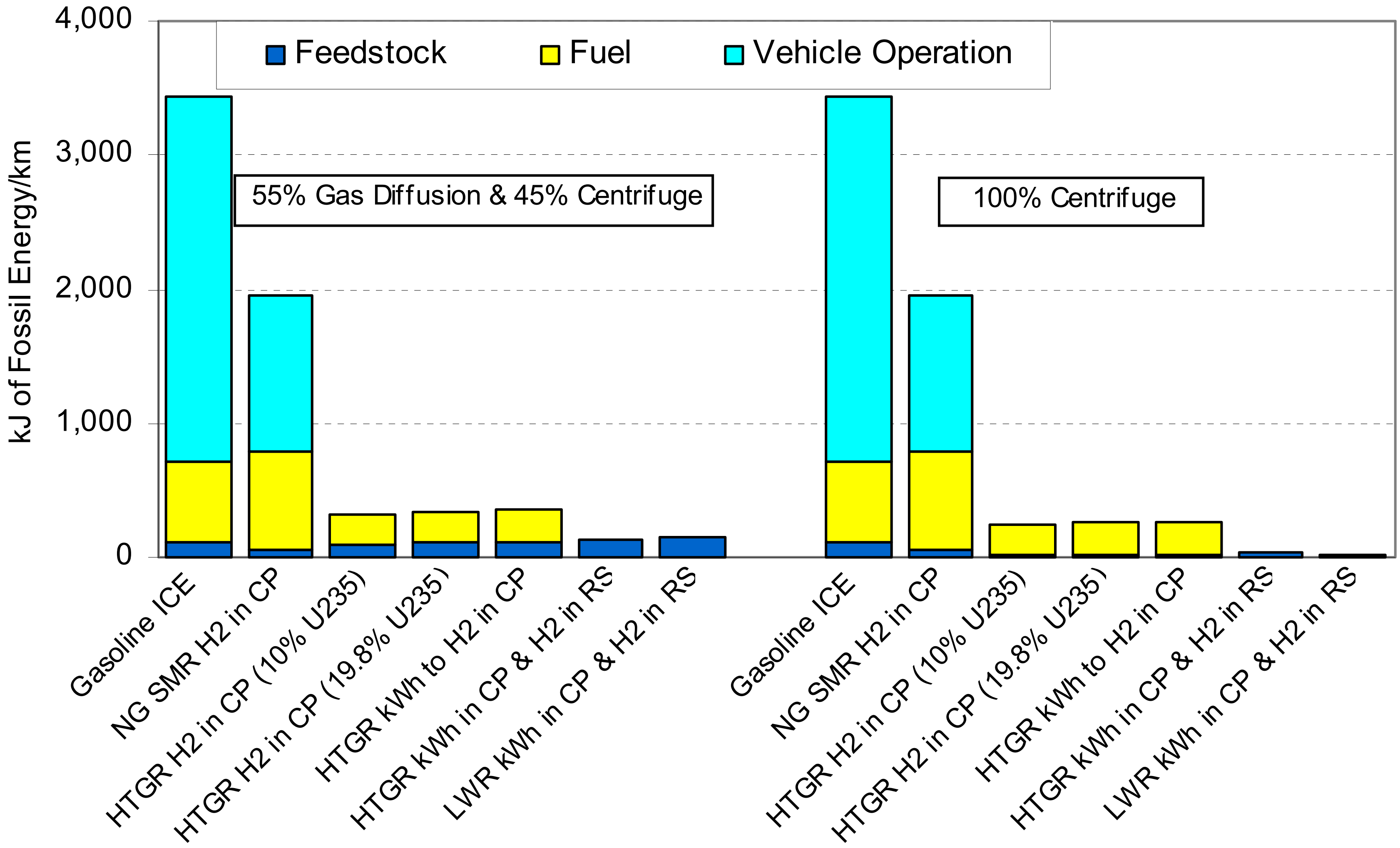
Well-To-Pump Results: GHG Emissions (Grams per MJ of H_2 at Fuel Pump)



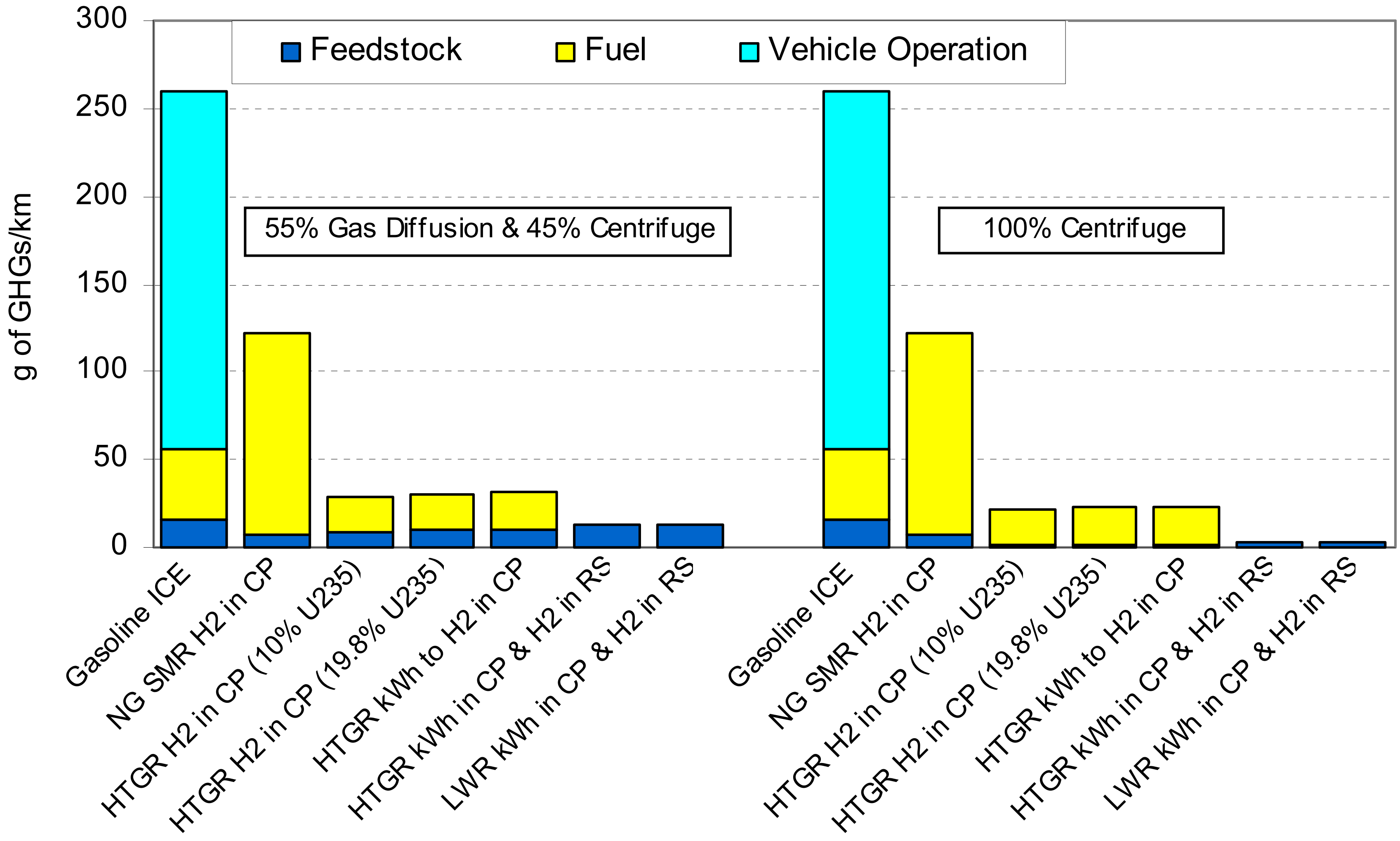
Well-To-Wheels Results: Total Energy Use (kJ/km)



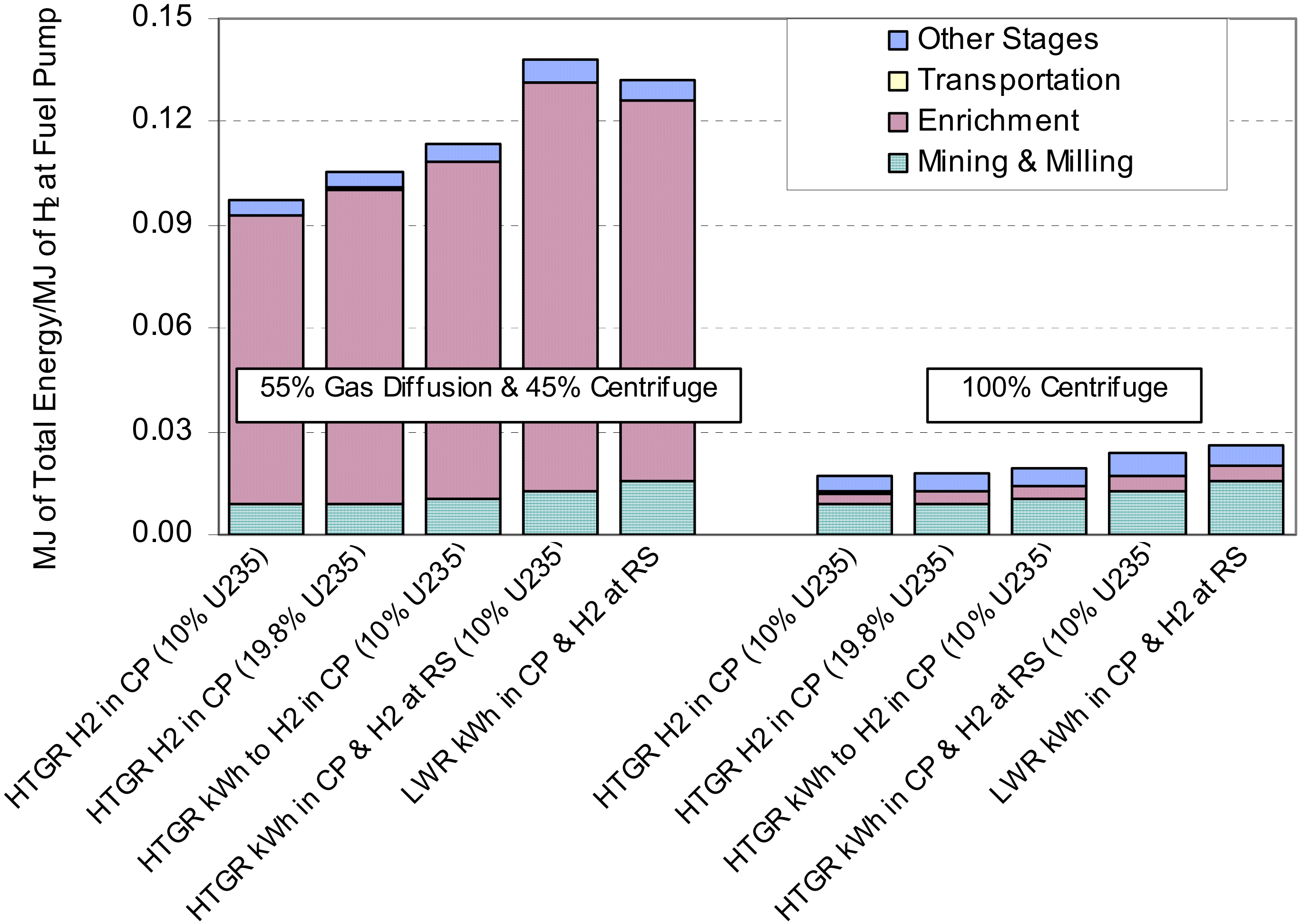
Well-To-Wheels Results: Fossil Energy Use (kJ/km)



Well-To-Wheels Results: GHG Emissions (g/km)



Gas Diffusion Enrichment Has the Large Energy Use



Conclusions

- **Significant reductions in GHG emissions and fossil fuel use are achieved by nuclear-based H_2 compared to NG-based H_2**
  - GHG emission reductions: 73-98%
  - Fossil energy use reductions: 81-99%
- **Well-to-wheels results also show large reductions by nuclear-based H_2 FCVs**
  - Compared to gasoline ICE Vehicles, nuclear H_2 FCVs achieve
    - GHG emission reductions of 88-99%
    - Fossil energy use reductions of 89-99%
  - Compared to NG H_2 FCVs, nuclear H_2 FCVs achieve
    - GHG emission reductions of 74-98%
    - Fossil energy use reductions of 82-98%
- **Key factors determining energy and GHG effects of nuclear H_2 FCVs**
  - Uranium enrichment technologies and their energy requirements
  - Electricity use for H_2 transportation and compression and electricity supply sources

Limitations of This Study

- **Nuclear waste transportation and disposal were not analyzed**
- **Mining, milling, and transportation of uranium ore and fuel from non-U.S. sources were not included**
- **Helium gas (used as coolant in HTGR) production and leakage (if any) were not considered**
- **Energy use and emissions of infrastructure-related activities (such as construction of plants) were not included for all fuel pathways**
- **Other reactor technologies were not evaluated**