An Energy Path Forward

—A Personal Perspective—

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Observation: There are Three Components to the Global Energy System

Energy Sources	Energy Storage	Energy Distribution
Nuclear	Water (Dams)	Electricity
Renewables	Chemical	Chemical
Fossil Coal Oil Natural gas	Fossil Coal Liquid fuels Natural gas	Fossil Coal Liquid fuels Natural gas

Constraints: Greenhouse gas impacts and dependency on foreign energy sources

A Future Energy Strategy

The Electric-Liquids Fuel Future

No Oil Imports by 2020

The New Electric Grid

Full Use of Nuclear, Renewables, and Coal Gasification with Carbon Dioxide Sequestration

Primary Energy Production

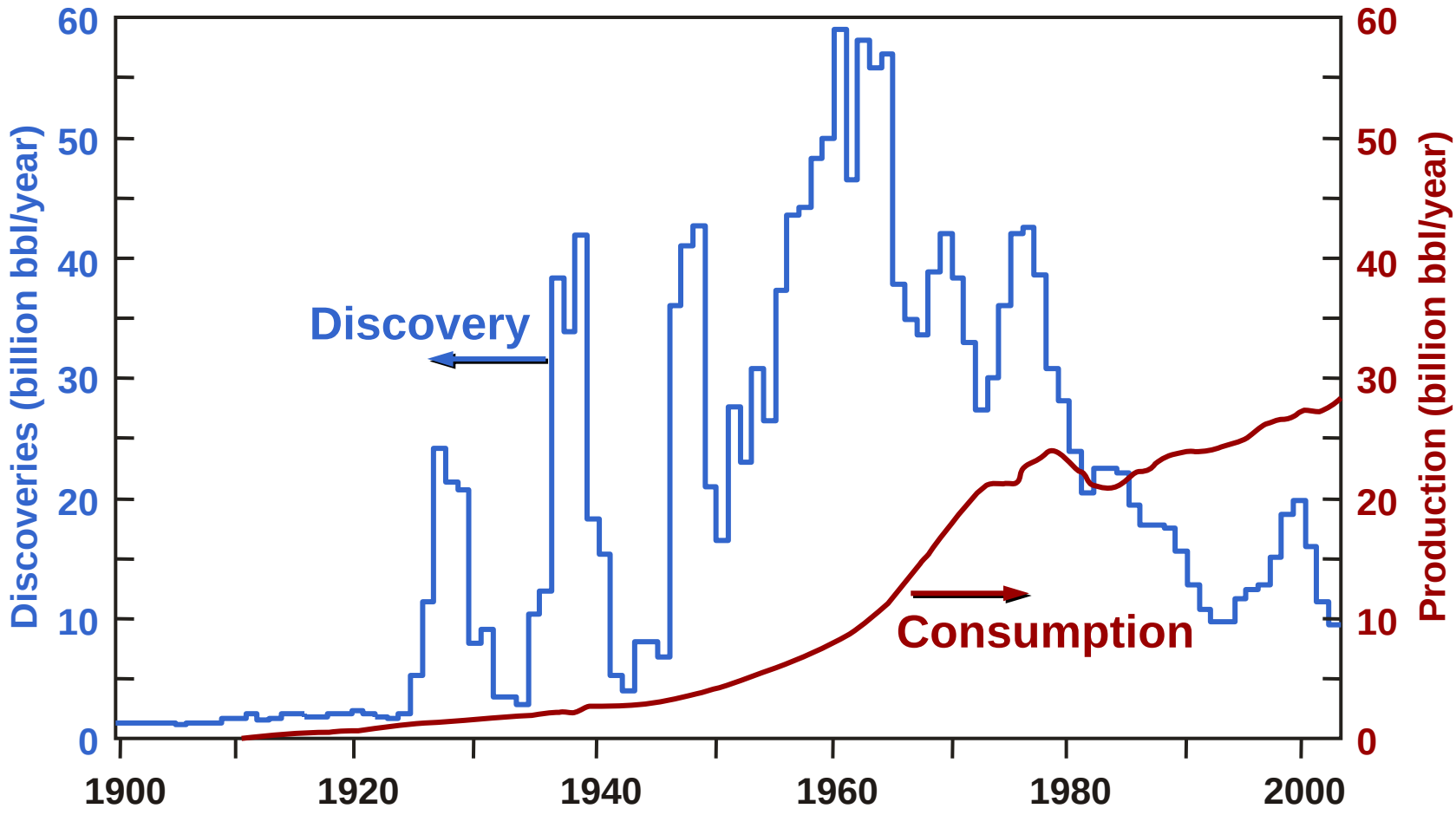
Clean Air and No Greenhouse Impacts

The Electric – Liquid-Fuel Future

No Oil Imports by 2020

Plug-in Hybrid Vehicles
Hydrogen-Rich Liquid Fuels

The Age of Oil for Fuels is Closing



Oil and Gas J.; Feb. 21, 2005

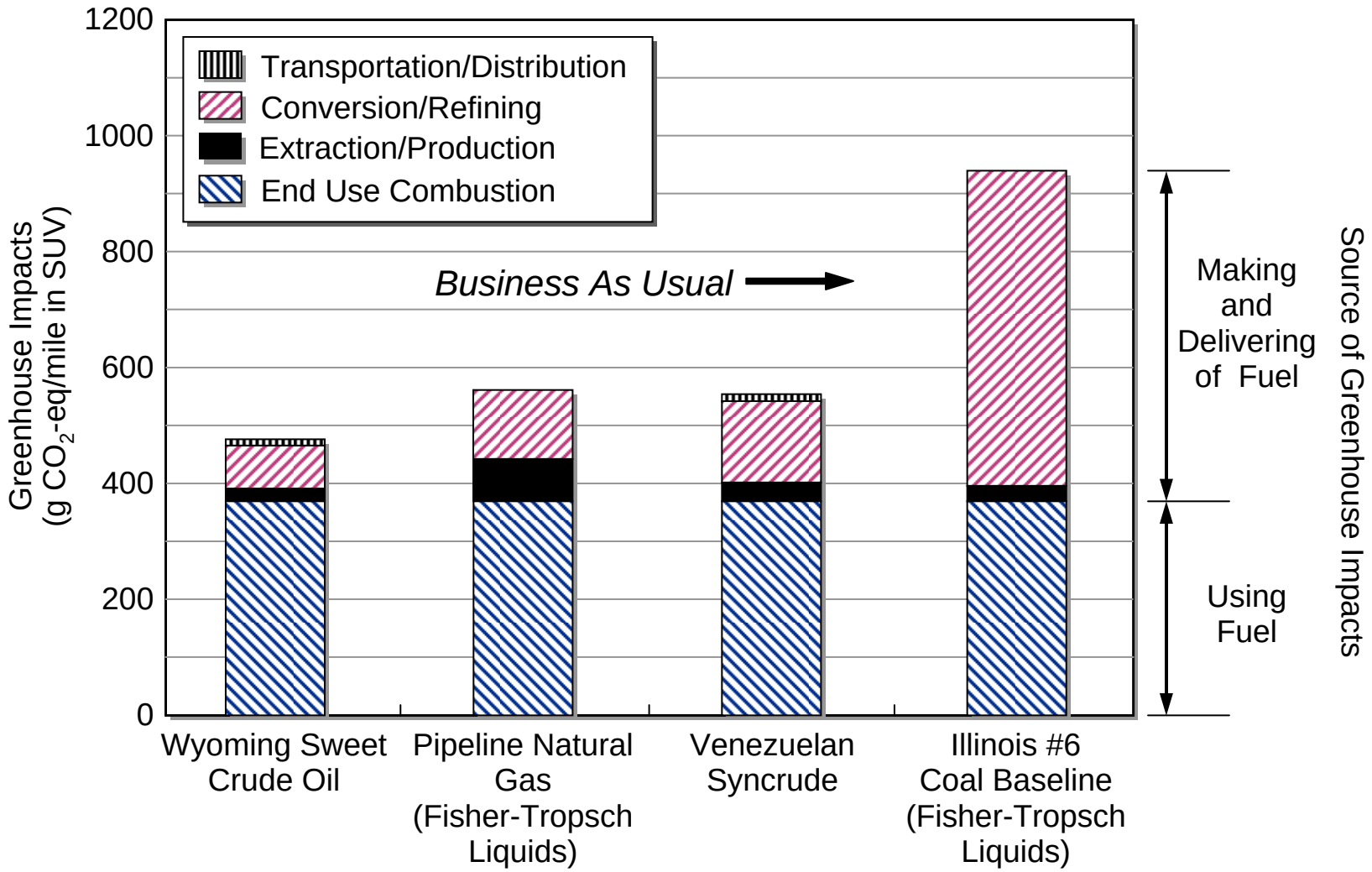
Conventional Futures: Liquid Fuels will be Made from Heavy Oils, Tar Sands, and Coal

(Lower Hydrogen-to-Carbon Ratios)

Syncrude Canada Ltd.
Tar Sands Operations

- **Tar sands, heavy oils and coal are converted to liquid fuels by:**
  - **Addition of hydrogen**
  - **Removal of carbon (usually with CO_2 to atmosphere)**
- **Implies massive increase in H_2 demand**
- **Traditional technologies imply major increases in CO_2 releases per vehicle mile (greenhouse-gas concern)**

Conventional Futures Imply Rapidly Increasing Greenhouse Emissions per Vehicle Mile Traveled



The Electric-Liquid Fuel Future
(New Roles for High-Temperature Reactors)

- **Plug-in Hybrid Cars and Light Trucks**
  - **Using electricity to replace half the fuel consumed by these vehicles**
  - **Electricity costs less than gasoline**
- **Hydrogen-Rich Liquid Fuels**
  - **Increasing gasoline and diesel fuel per barrel of oil**
  - **Starting the transition to a no-greenhouse-gas liquid fuel future**

Strategy I: Hybrid Engines Enable Plug-In Hybrid Electric Vehicles (PHEVs)

Replacing Half the Gasoline in Cars and Light Trucks with Electricity

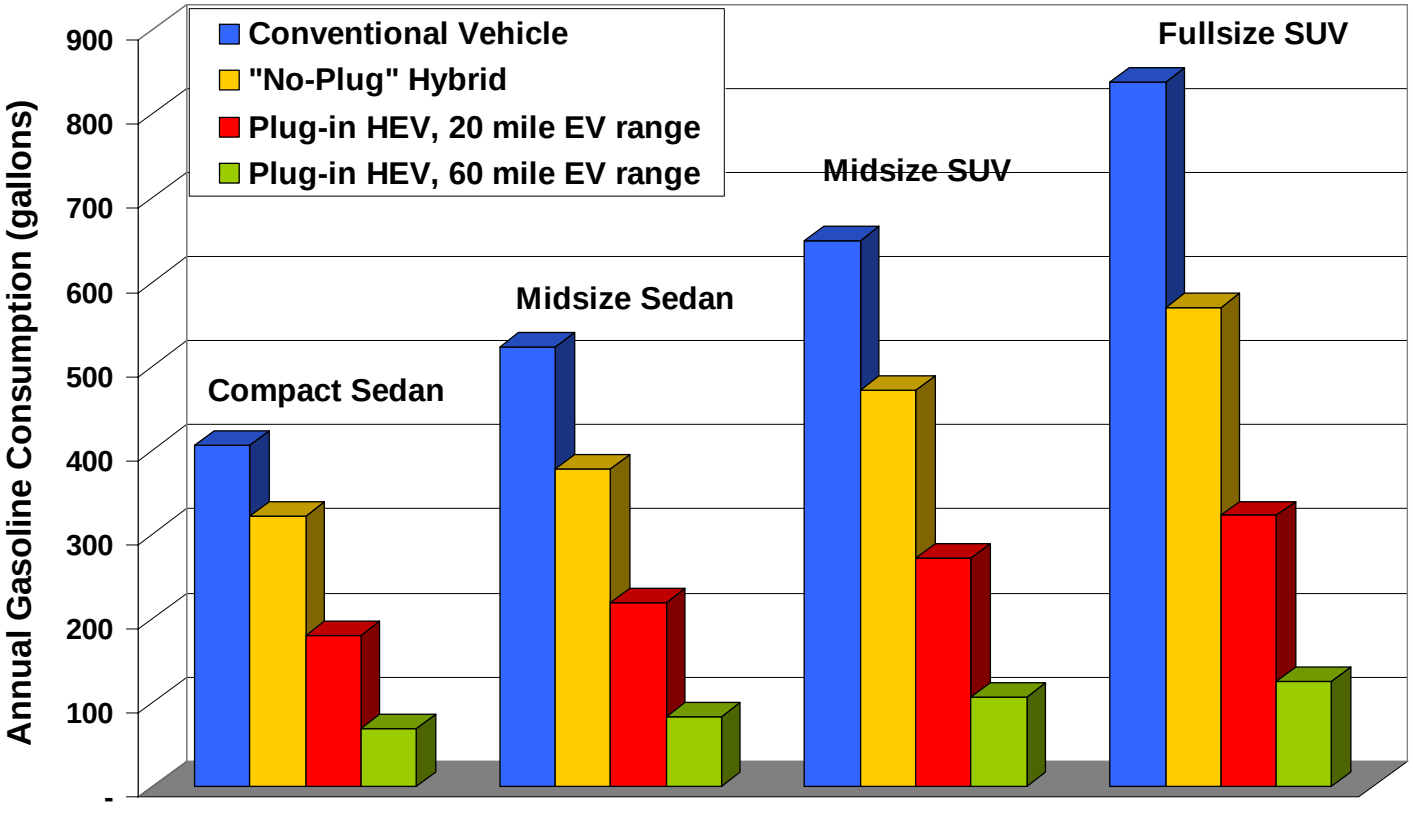
Prototypes in the Field

- **Electric cars have two major battery-connected limitations**
  - **Limited range**
  - **Recharge time (Gasoline refueling rate is ~10 MW)**
- **Hybrid vehicle option**
  - **Electric drive for short trips**
  - **Hybrid (gasoline and electricity) for long trips**
  - **Recharge battery over night**
- **Massive reduction in oil consumption**
- **Alternative to the strategic petroleum reserve**
- **Cuts greenhouse emissions by using clean electric sources**

Courtesy of the Electric Power Research Institute

PHEV Annual Gasoline Consumption

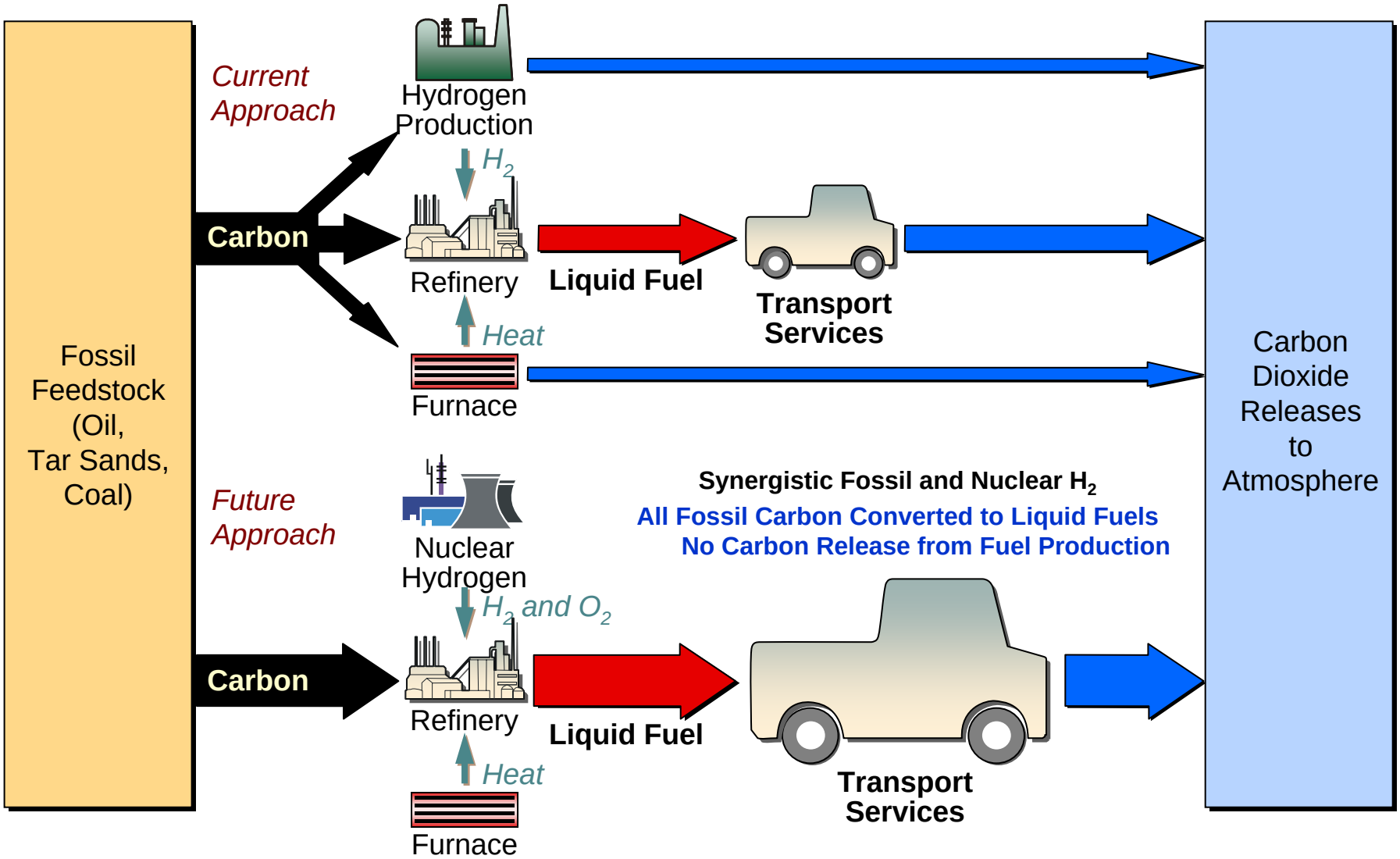
Connecting Transportation to the Electric Grid and Cutting Fuel Consumption in Half by 2020*



*PHEV would also replace the Petroleum Strategic Reserve. With oil shortages, there would be strong incentives to plan trips from electric plug to electric plug. This would be inconvenient but would dramatically drop gasoline consumption.

Courtesy of the Electric Power Research Institute

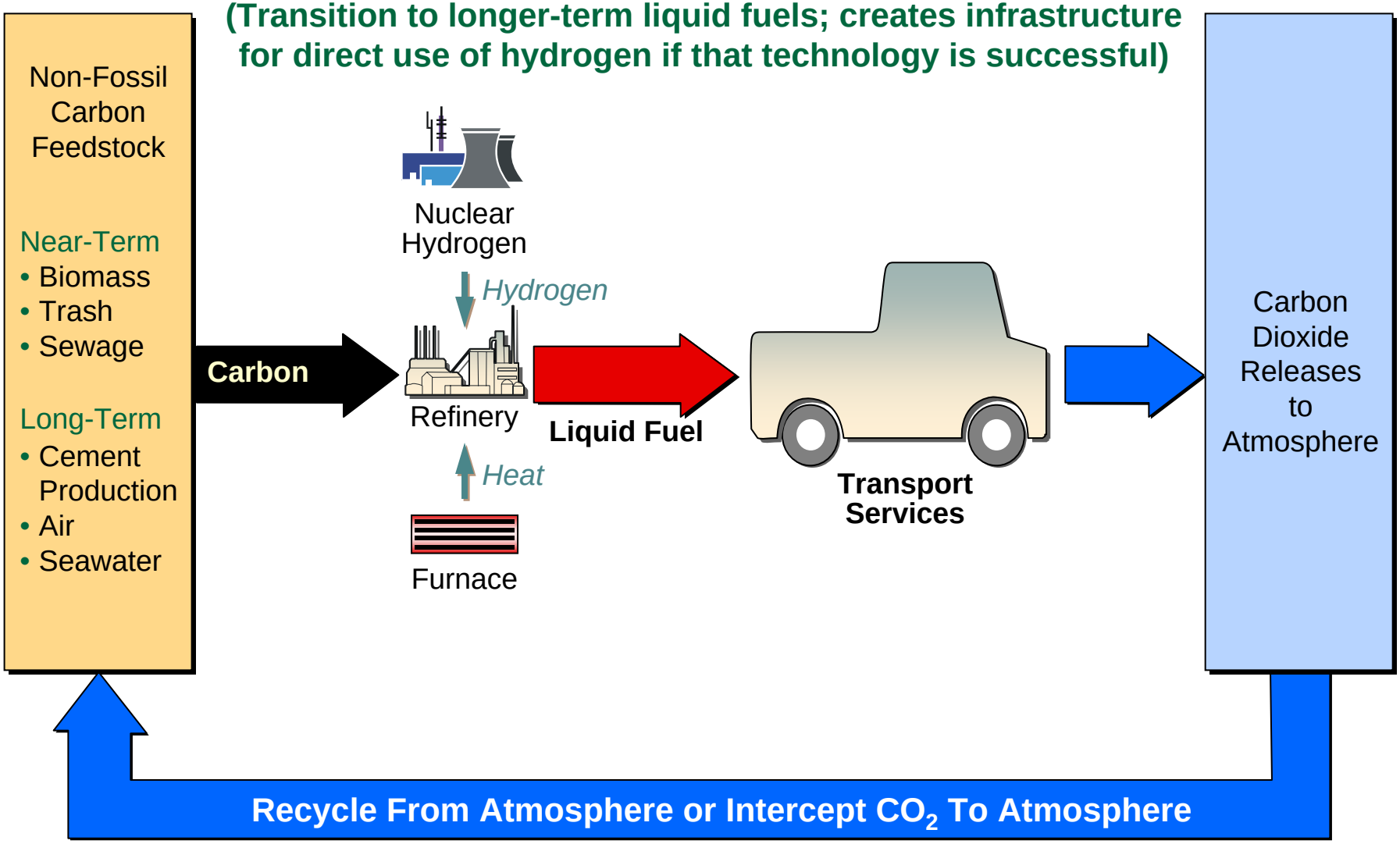
Strategy II: Hydrogen for Increasing Liquid Fuel Per Unit of Feedstock and Reduce Emissions



Hydrogen sources: nuclear, renewables, and coal with carbon dioxide sequestration

Zero-Greenhouse-Gas Liquids Fuel Strategy

(Transition to longer-term liquid fuels; creates infrastructure for direct use of hydrogen if that technology is successful)



Electric-Liquid Fuel Future
Path Forward

- **Plug-in Hybrids**
  - Encourage hybrids and plug-in hybrids
  - Technology development:
    - Better auto energy storage systems (batteries, flywheels, and capacitors)
    - Electric grid transmission for plug-in hybrid electric load

- **Hydrogen-Rich Liquid Fuels**
  - Encourage upgrading carbon stocks with hydrogen (rather than thermal cracking)
  - Technology development: Hydrogen initiative emphasize on hydrogen production for liquid-fuel production

The New Electric Grid

Enable the Full Use of Nuclear, Renewables, and Coal Gasification with CO_2 Sequestration

Bulk Electricity Storage

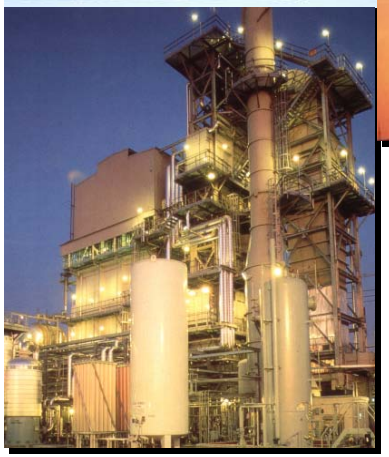
Electric Grid Uses Fossil Fuels to Match Generation with Demand

(Limits Use of Nuclear, Renewables and Coal Gasification)

Continuous Operation
(High Capital Cost/Low Operating Cost)

Nuclear

Renewable

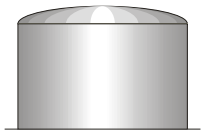


Coal Gasification

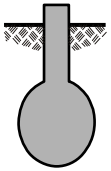
Variable Operation
(Low Capital Cost/High Operating Cost)

Power Conversion

Coal Piles

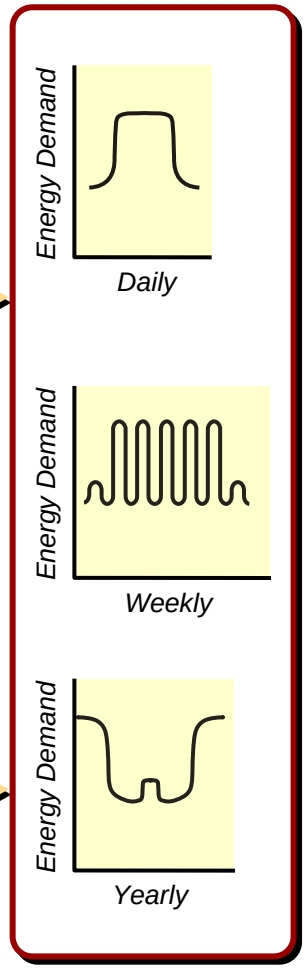


Oil Storage



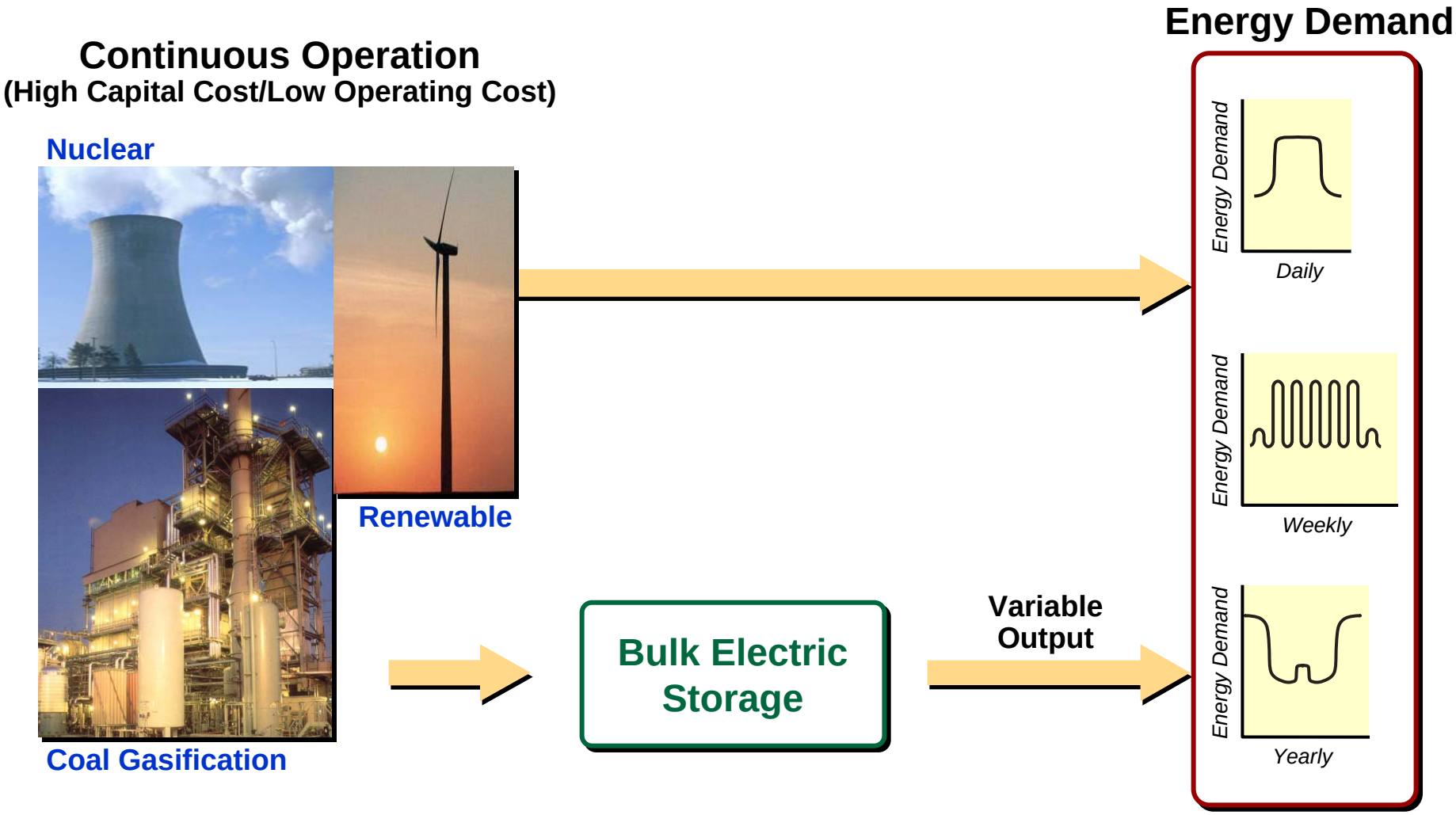
Underground Natural Gas Storage

Energy Demand



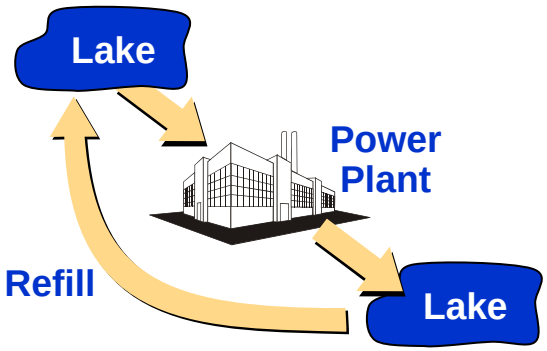
The New Electric Grid

(Unlimited Use of Nuclear, Renewables, and Coal Gasification with Sequestration)



Bulk Electric Storage Options

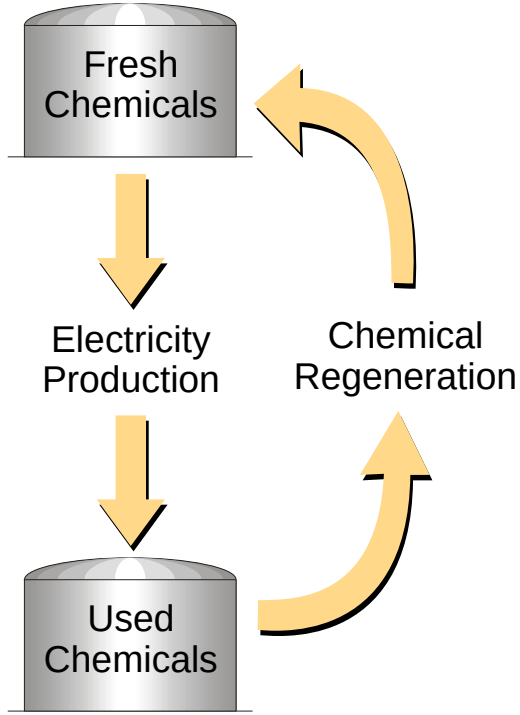
Daily



TVA Raccoon Mountain

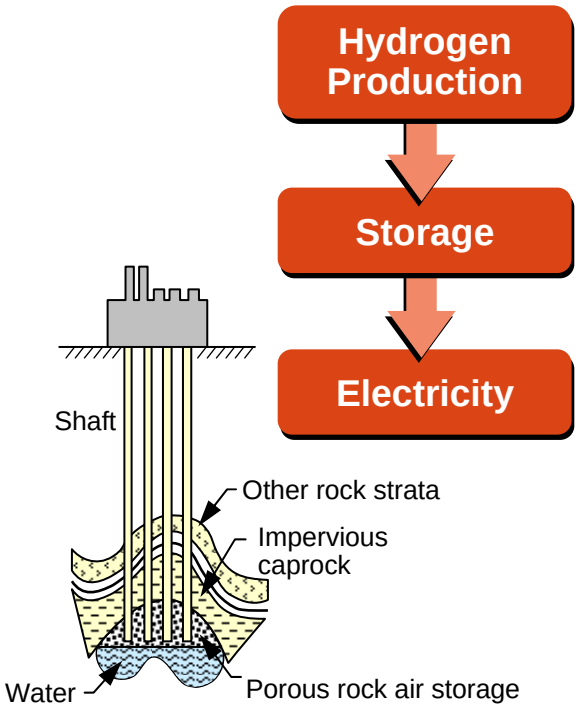
Hydro Pumped Storage

Weekly



Chemical Flow Batteries

Monthly



Hydrogen
(Store like natural gas)

Lower Energy Storage Costs

The New Electric Grid
Path Forward

- **Encourage bulk electric storage to enable full use of capital intensive, low-operating cost (1) renewables, (2) nuclear, and (3) goal-gasification combined-cycle plants**
  - **Pumped hydro storage**
  - **Compressed air storage**

- **Technology: Develop new bulk electric storage technologies**
  - **Chemical flow batteries**
  - **Bulk hydrogen storage and conversion to electricity**
  - **Other**

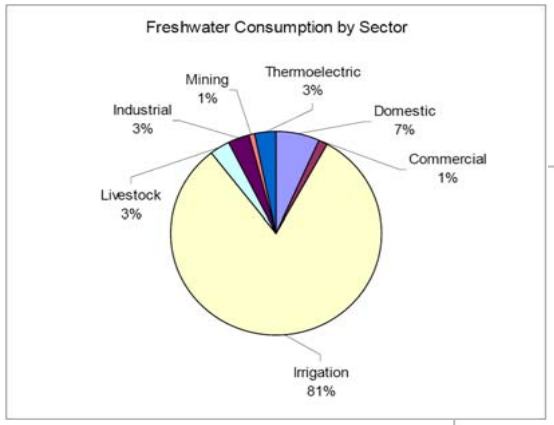
Primary Energy Production

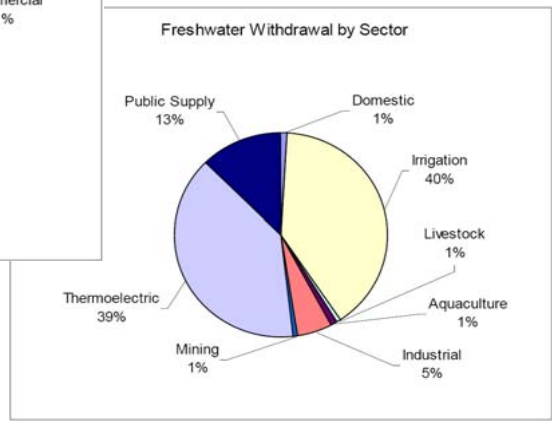
Clean Air and No Greenhouse Impacts

Let a Thousand Flowers Bloom

Nuclear
Renewables
Coal Gasification with Sequestration
Conservation (Negative Energy)

Nuclear: Light-Water Reactor (LWR) Today; High-Temperature Reactor by 2025; Nuclear Fuel Recycle and Breeders for the Long-Term

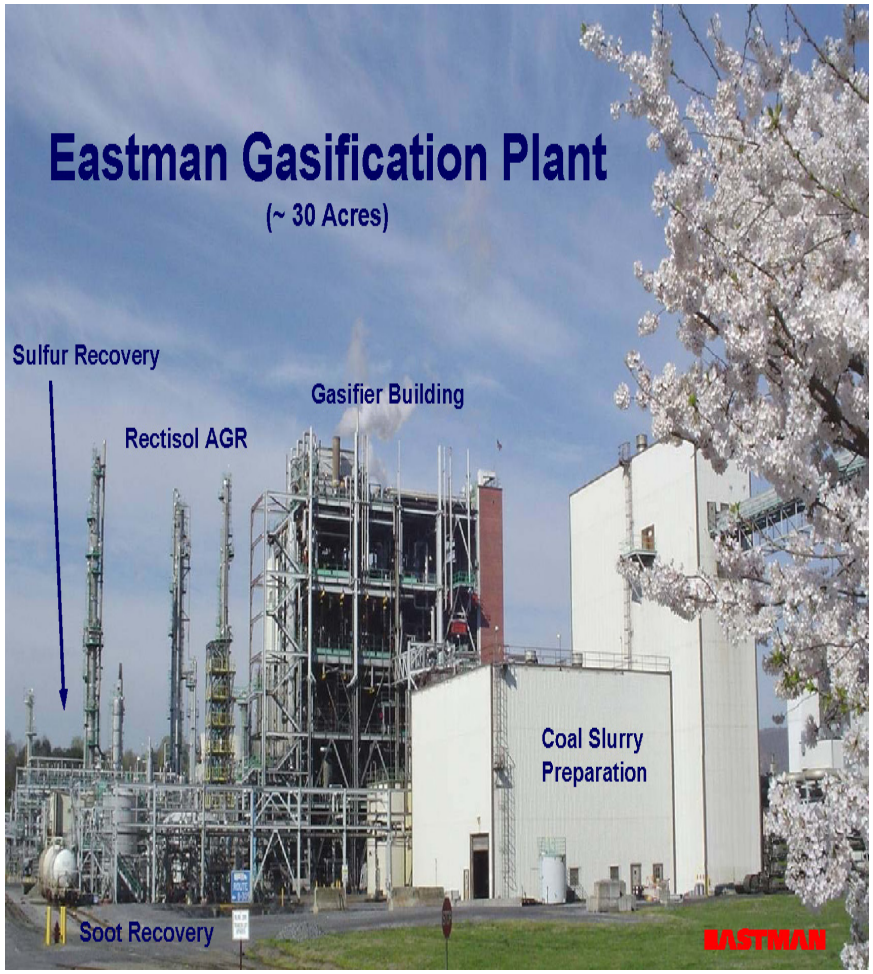




- **Near-Term**
  - **25 GW(e) LWRs by 2025**
  - **License Yucca Mountain repository (initially for storage and then disposal)**
- **Mid-Term: High Temperature Reactors**
  - **Hydrogen production for liquid fuels production**
  - **High-efficiency electricity production to minimize water usage**
    - **Major conflicts between water and energy use**
    - **Ease siting by eliminating large water usage**
- **Long-Term**
  - **Spent nuclear fuel recycle and breeder reactors**

Integrated Coal Gasification Combined Cycle (IGCC)

The Doorway to Clean Coal Electricity , Hydrogen, Reduced Natural Gas Consumption, and Carbon Dioxide Sequestration



- Used in the chemical industry with operating prototype electric plants for electricity production
- Potential for 80 GW(e) of new IGCC by 2025
  - Cleaner than traditional coal plants
  - Higher efficiency
- Retrofit of natural-gas-fired combined cycle plants
- The enabling technology for
  - Coal to hydrogen plants (existing commercial technology)
  - Electricity from coal with carbon dioxide sequestration

Renewables: Near-Term, Mid-Term, and Long-Term

- Encourage renewables
- Technology R&D
  - Near-term
    - Solar power-tower demonstrations
  - Mid-term
    - Biomass to liquid fuels with low-grade feedstocks
    - Biomass with hydrogen upgrading to liquid fuels
  - Long-term
    - Solar cells
    - Solar hydrogen production

Conservation

- **Near-term need: Energy efficient codes and standards**

- **Technology R&D**
  - **Solid-state lights**
  - **Superconducting electrical systems**
  - **Out-of-box systems**

Potentially Achievable Goals

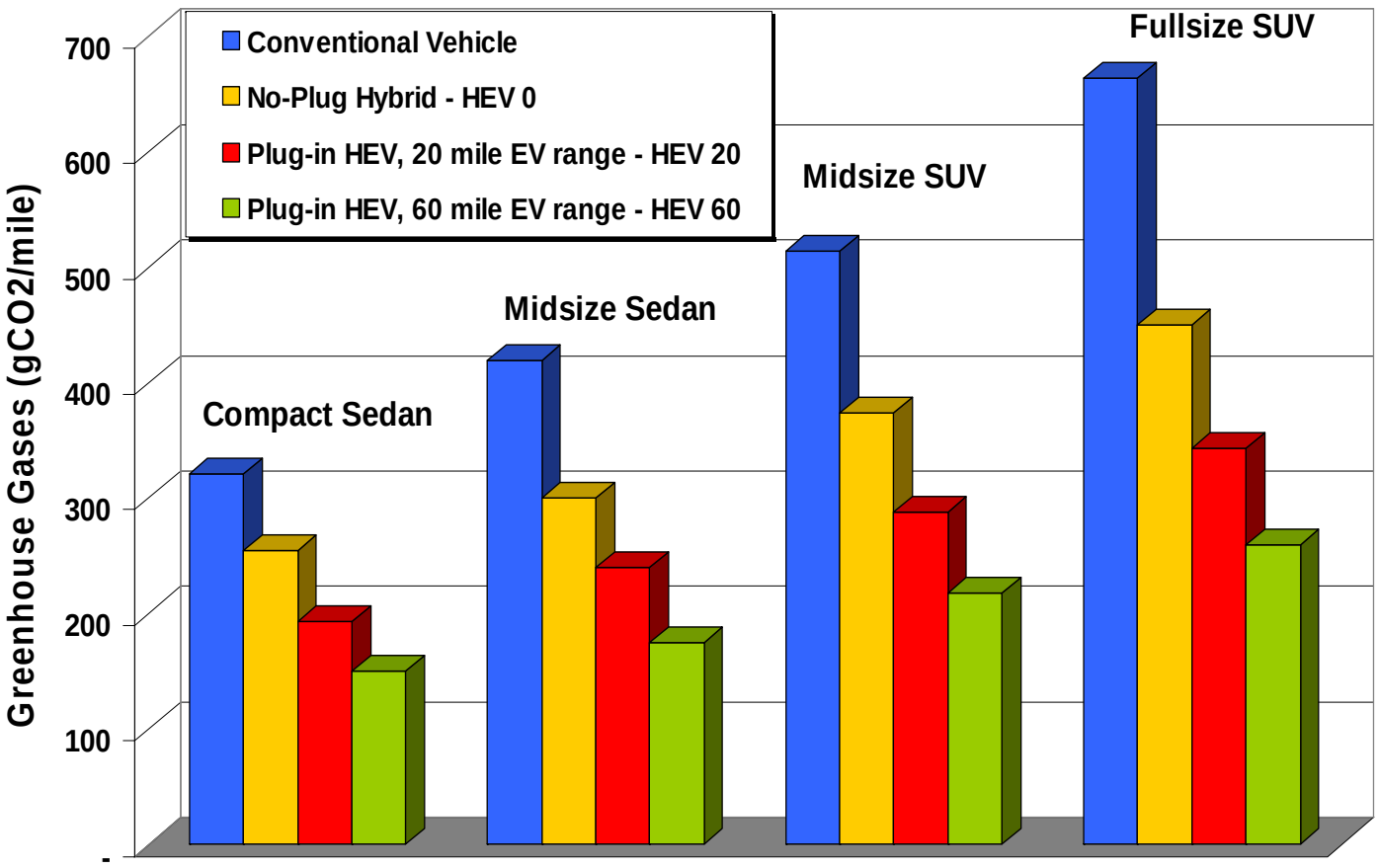
- No North American oil imports by 2025
  - Hybrids
  - Alternative liquid fuels (includes Canadian Tar Sands—at one million barrels per day and going to 5 million barrels per day)
- Clean electricity; kill off greenhouse emitters
  - Nuclear
  - Fossil with sequestration
  - Renewables

END

END

END

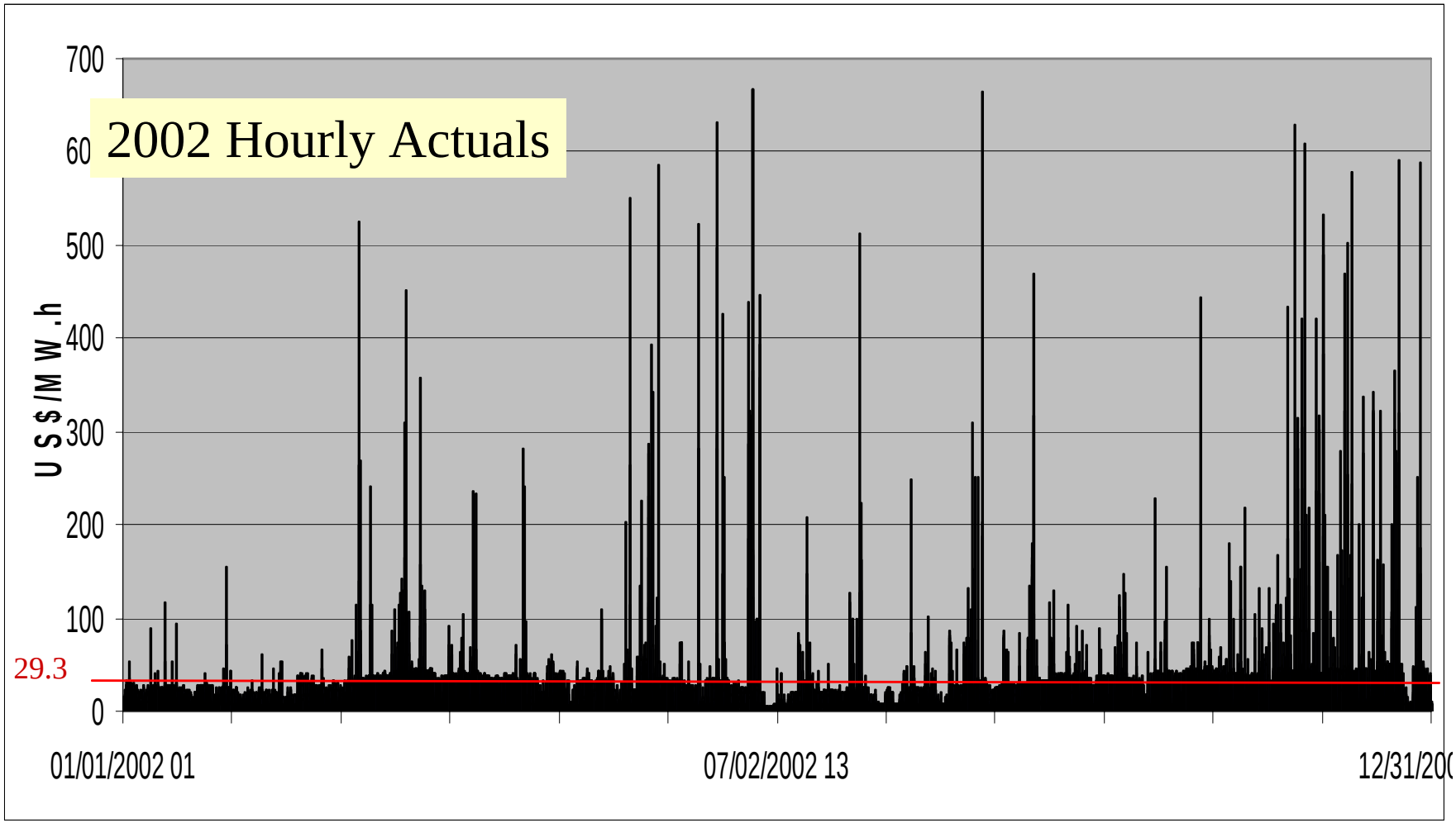
Well-to-Wheels Greenhouse Gas Emissions for Different Options



Courtesy of the Electric Power Research Institute

The Price (and Cost) of Electricity at Times of Peak Demand is High

(Premium-Priced Electricity)



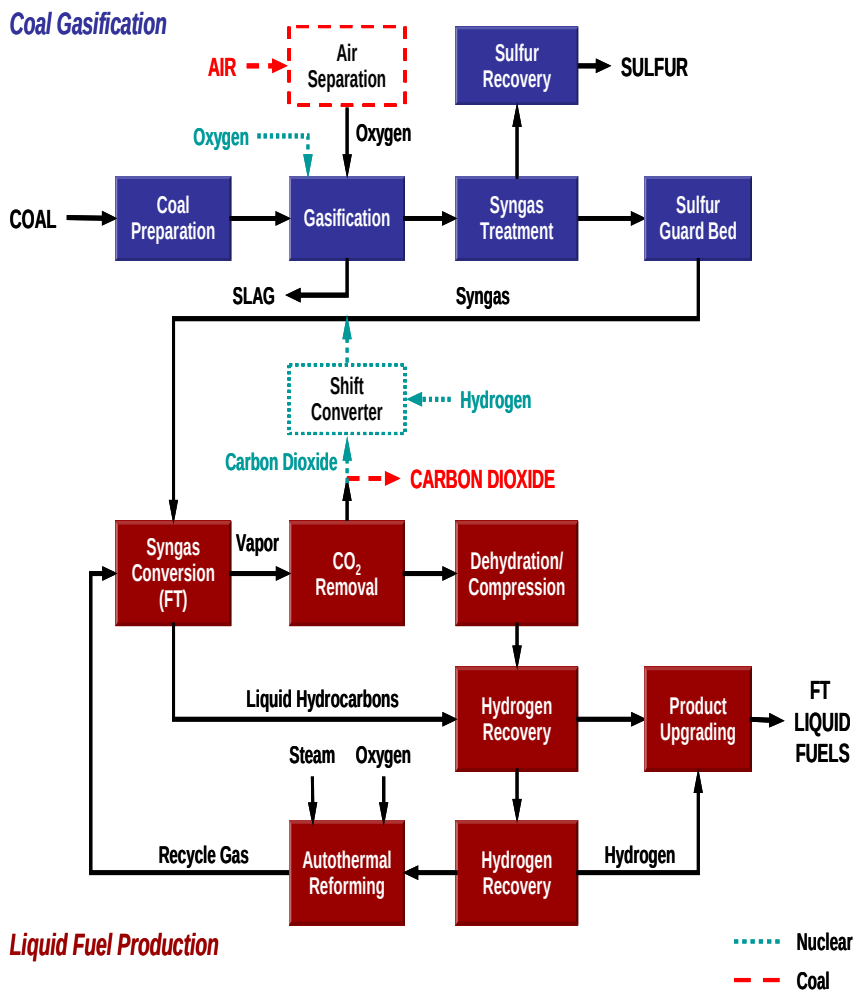
[Alberta Power Pool (US$/MW-h)]

Different Hydrogen Sources have Different Characteristics

Energy Source	Scale	O_2	Siting Limits
Nuclear	Large (Centralized)	Yes	Population; Seismic
Fossil	Variable	No	Fuel Availability; CO_2 Disposal
Solar	Small (Distributed)	Variable	Energy source

H_2 Production Systems Favored That Match Market Needs

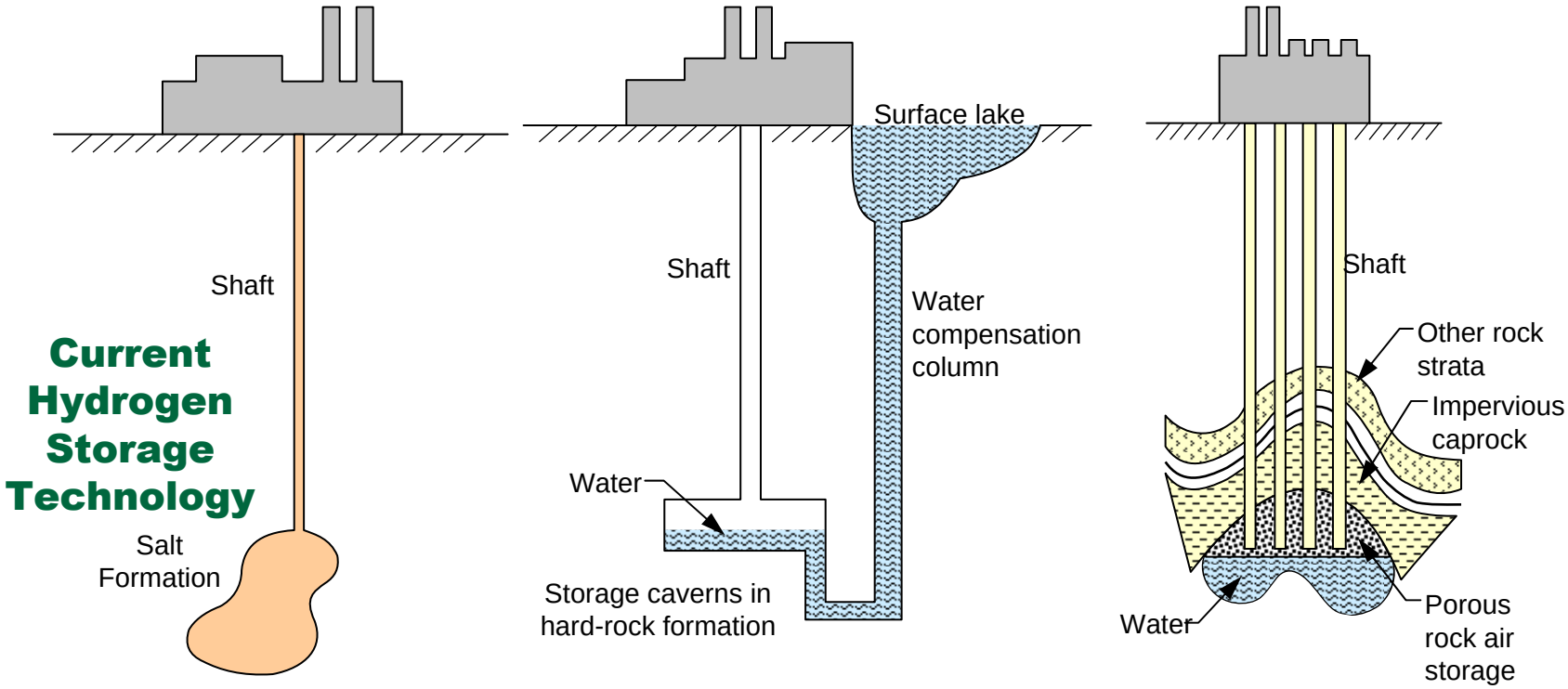
The Fischer-Tropsch (FT) Process Converts Coal and Other Feedstocks to Liquid Fuels



- The FT process is the preferred liquefaction process
  - Large experience base
  - Yields high-quality fuels
- Nuclear H_2 outputs <u>match</u> FT needs
  - H_2
  - O_2
  - Large scale

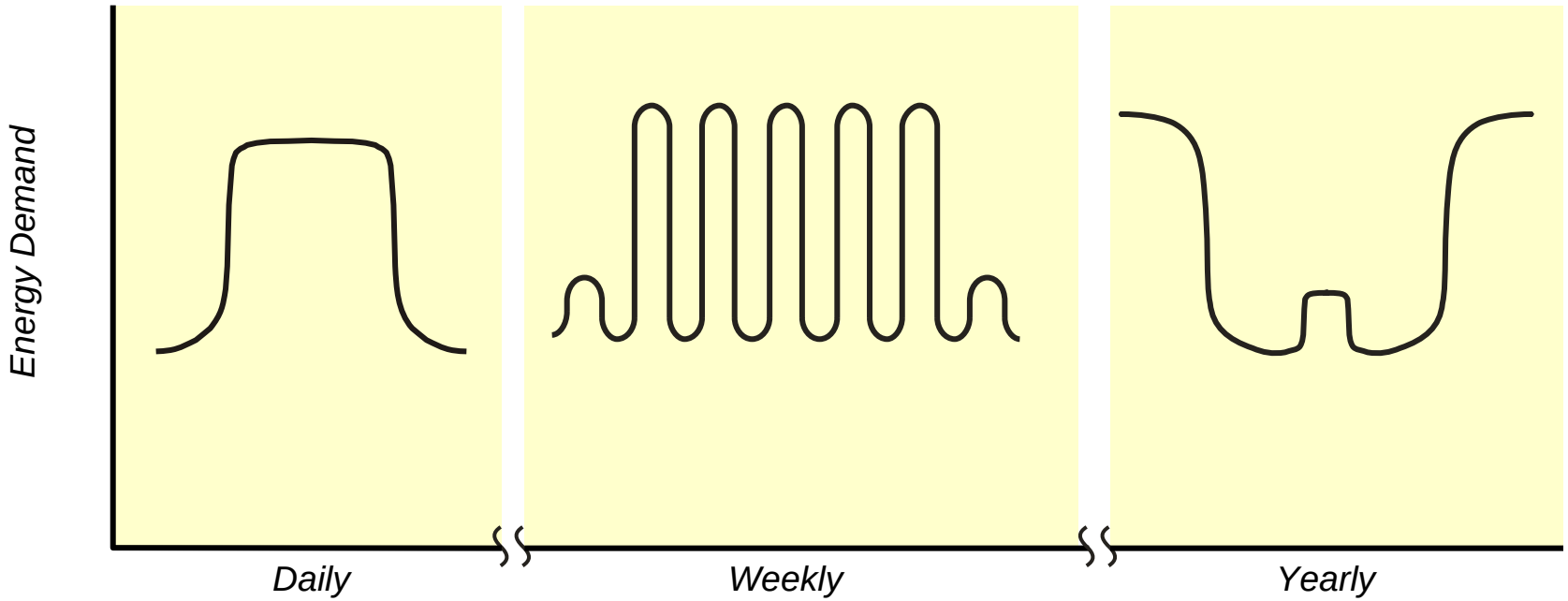
Hydrogen can be Stored Like Natural Gas

(Potential for Daily, Weekly, and Seasonal Storage to Use to Make Electricity at Times of Peak Demand)

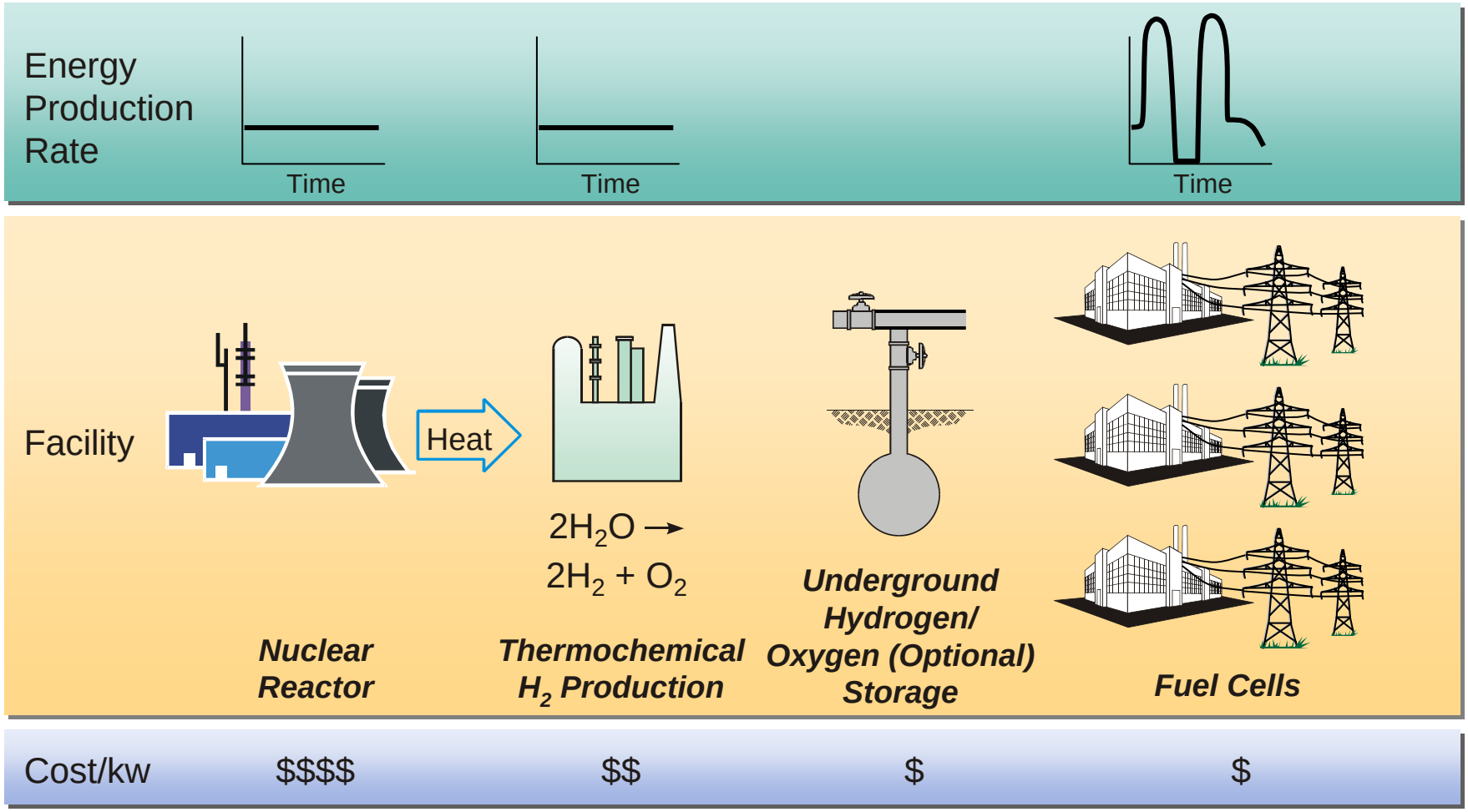


Stored Natural Gas In the U.S. Equals 1/3 of Annual Consumption

Energy Demand Varies with Time-of-Day, Weekly, and Yearly



Peak Electric Nuclear System (PENS)

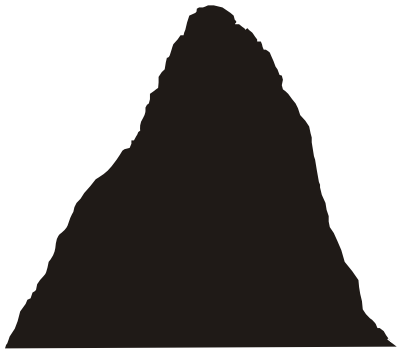


C. W. Forsberg, *Nuclear Hydrogen for Peak Electricity Production and Spinning Reserve*, ORNL/TM-2004/194, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

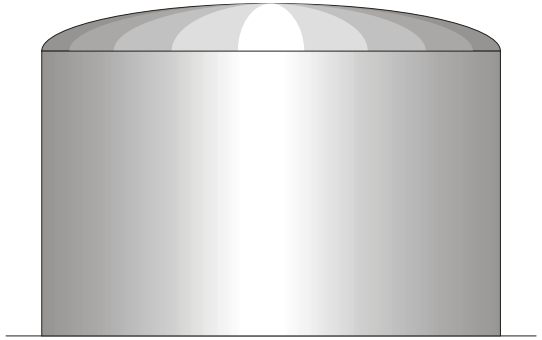
Stored Fossil Fuels are Used to Meet Variable Energy Demands

(Relatively Low Capital-Cost Equipment Converts Fossil Fuels to Electricity)

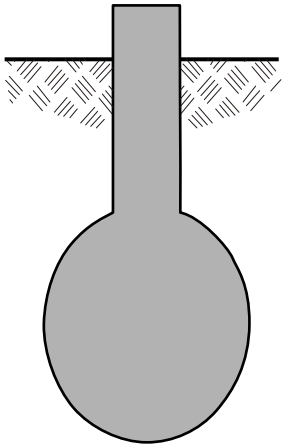
Coal Piles



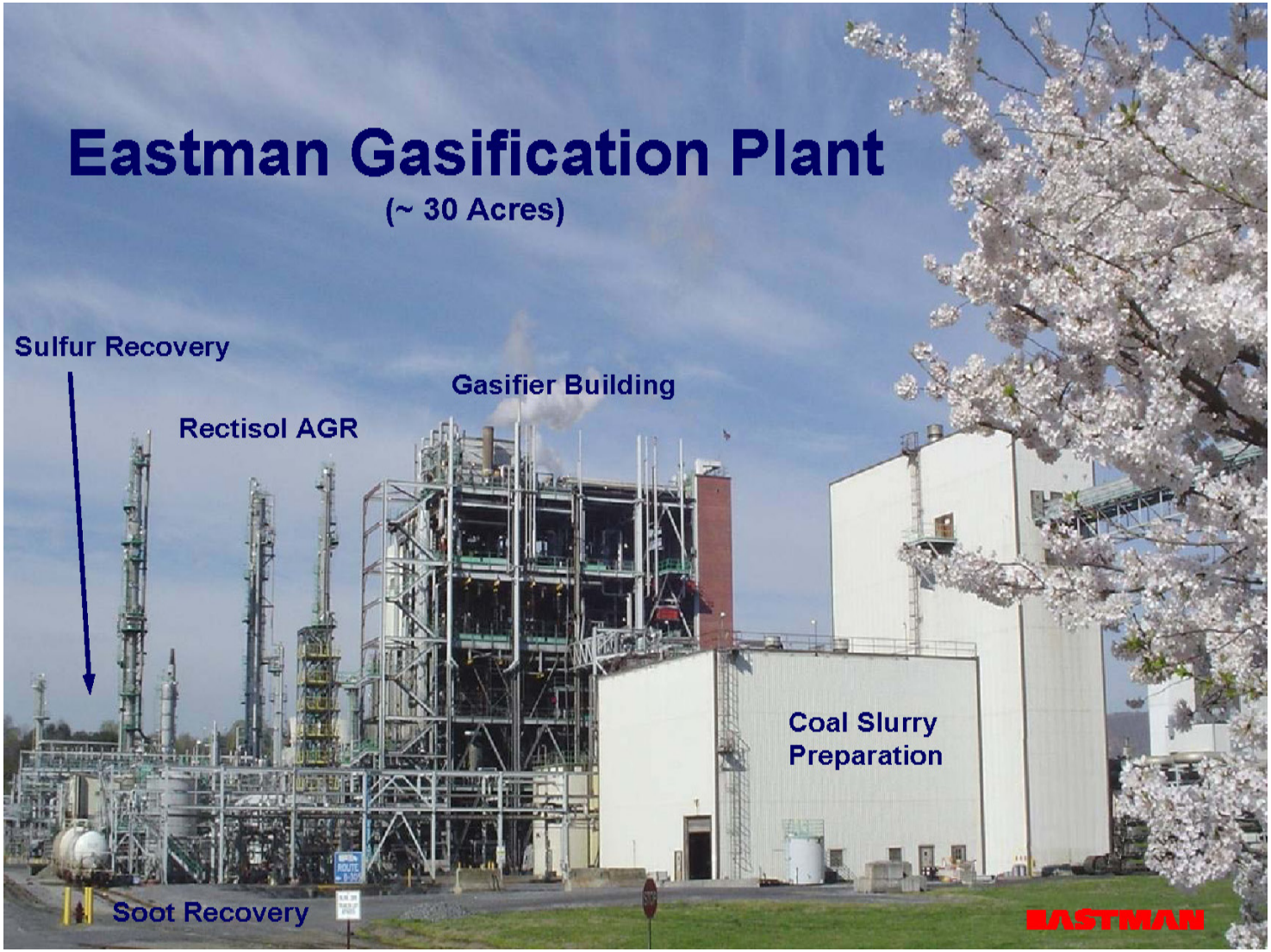
Oil Storage



Underground Natural Gas Storage



Production of Syngas by Coal Gasification



Path Forward for Energy Generation

Energy Source	Technology	Application
Nuclear	High-Temperature Reactors	Hydrogen Electricity With Dry Cooling
Fossil	Integrated Coal Gasification with Carbon Dioxide Sequestration	Hydrogen Electricity
Renewables	Multiple	Hydrogen (High-Risk) Electricity