U.S. Strategic Implications of Plentiful, Low Cost Natural Gas

Presented to the Hydrogen and Fuel Cell Technical Advisory Committee

Lawrence D. Burns

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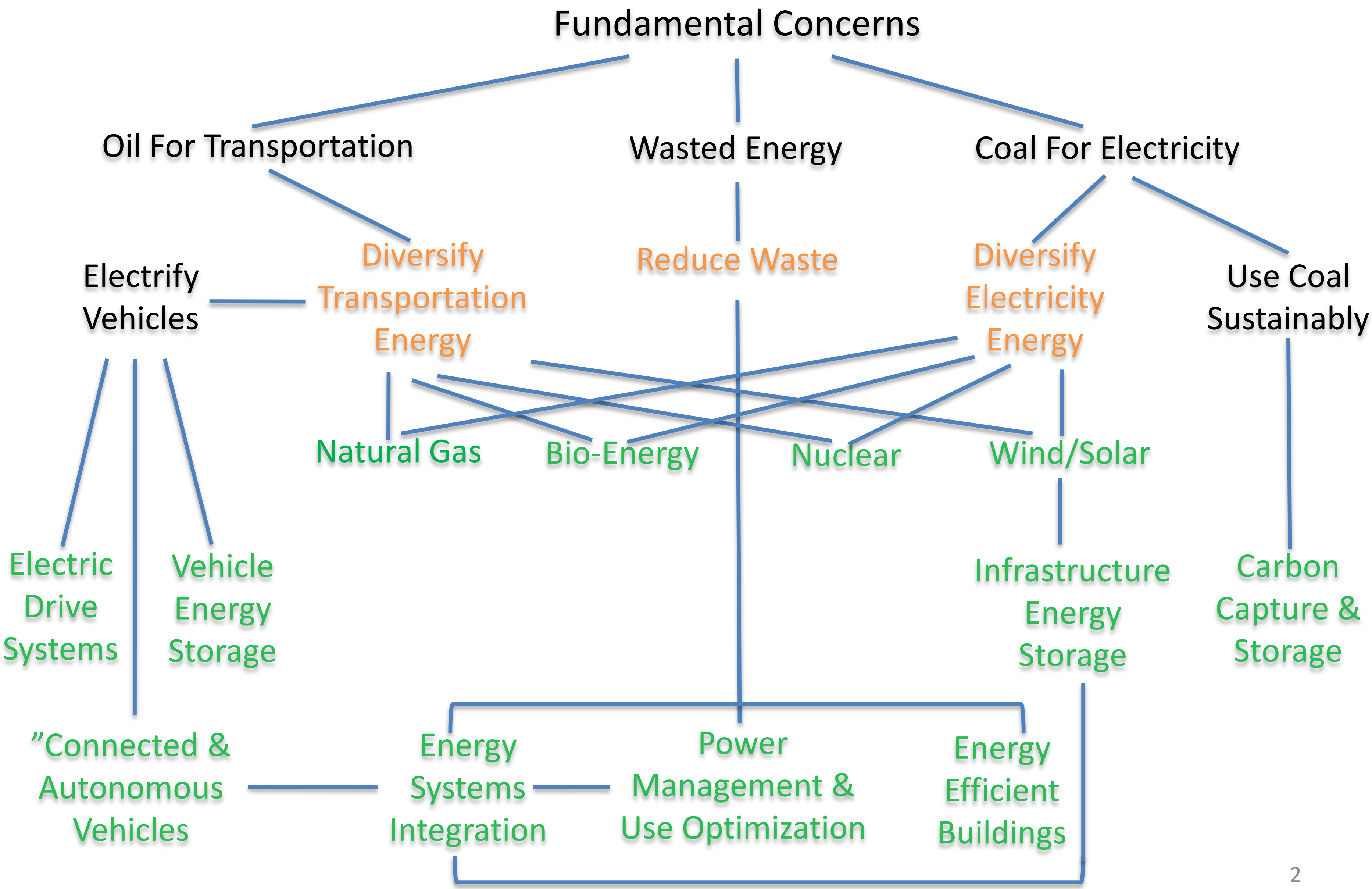
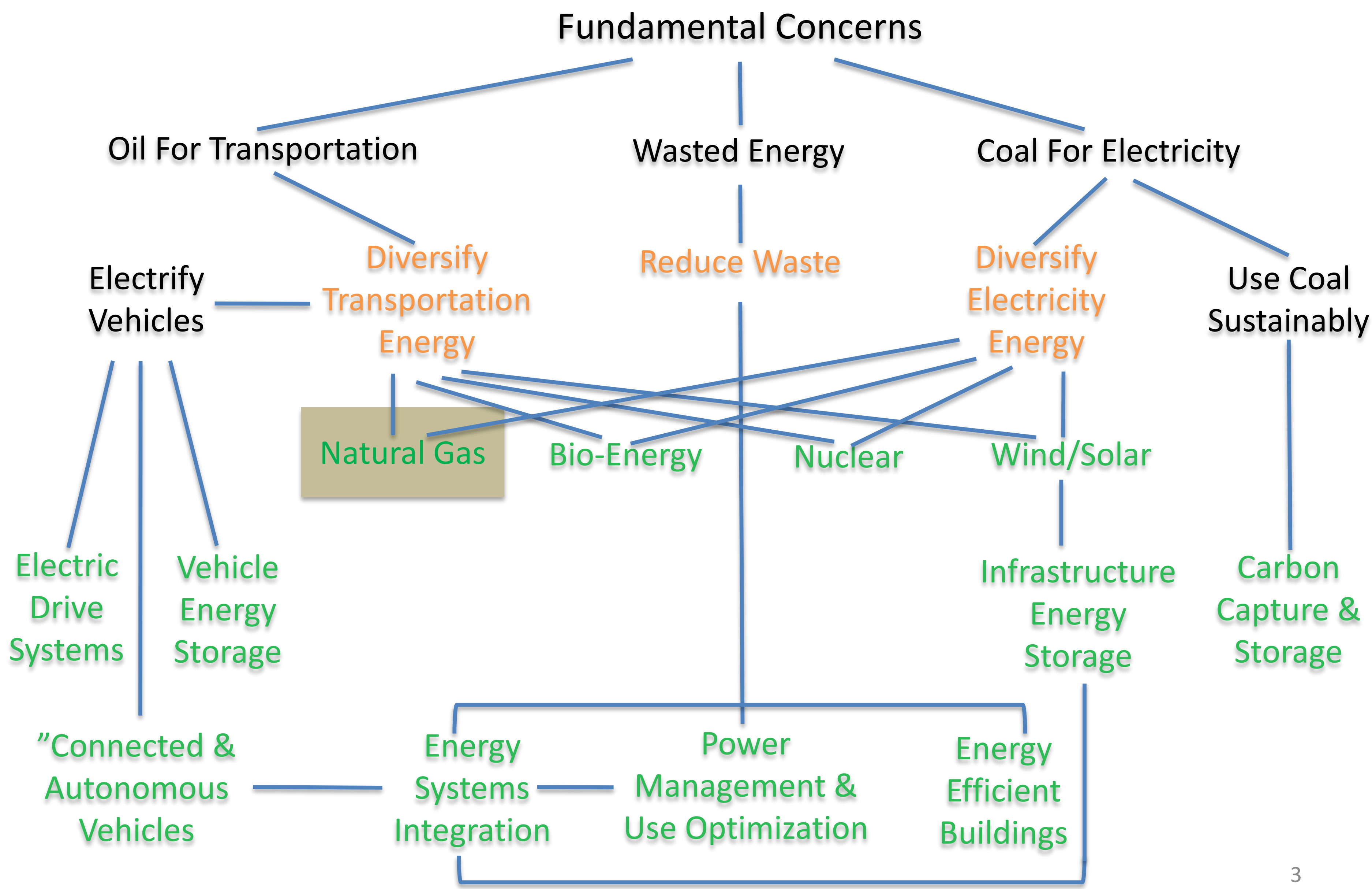
Key Drivers and Opportunities



Key Drivers and Opportunities

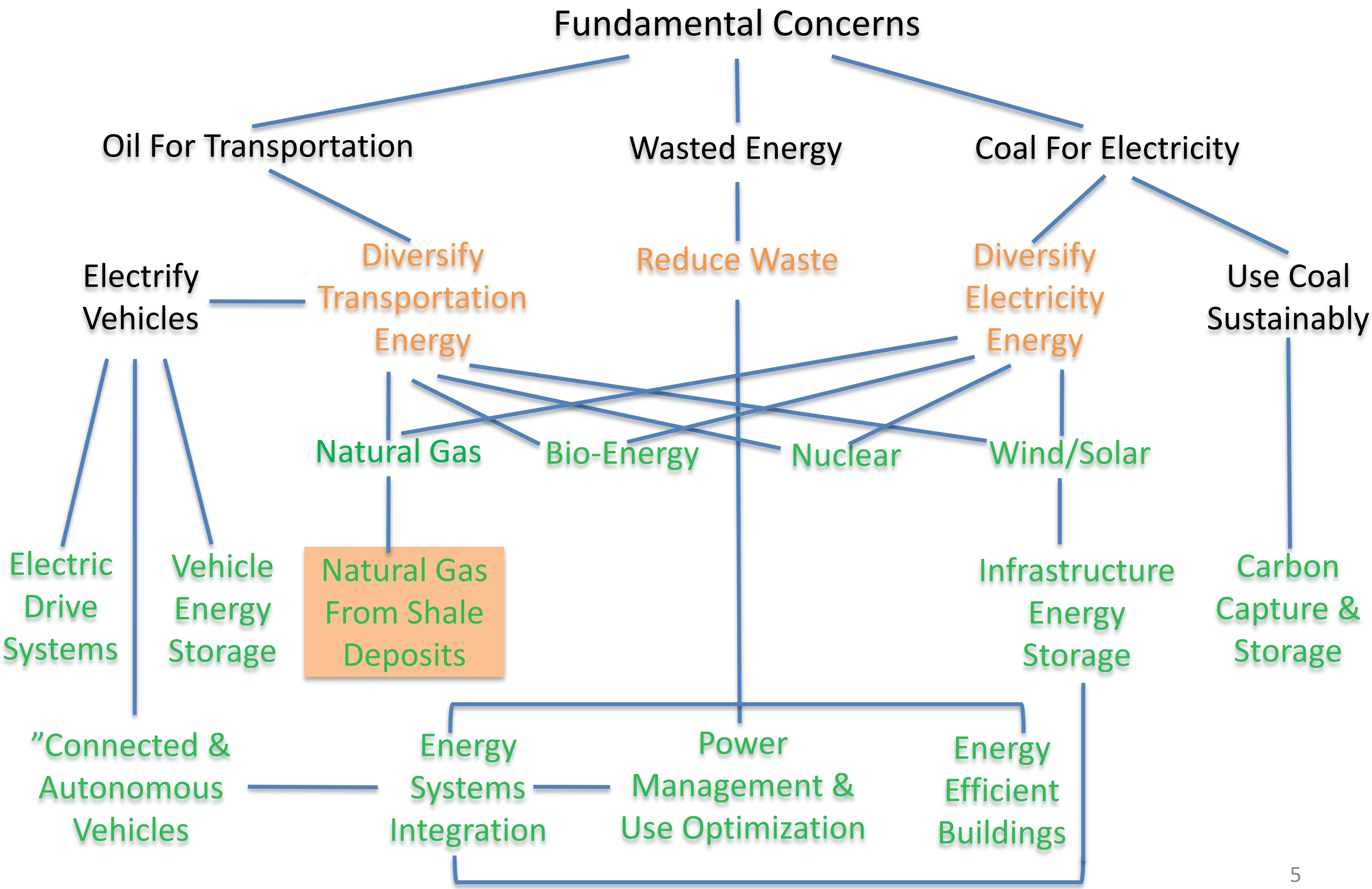


Natural Gas Benefits

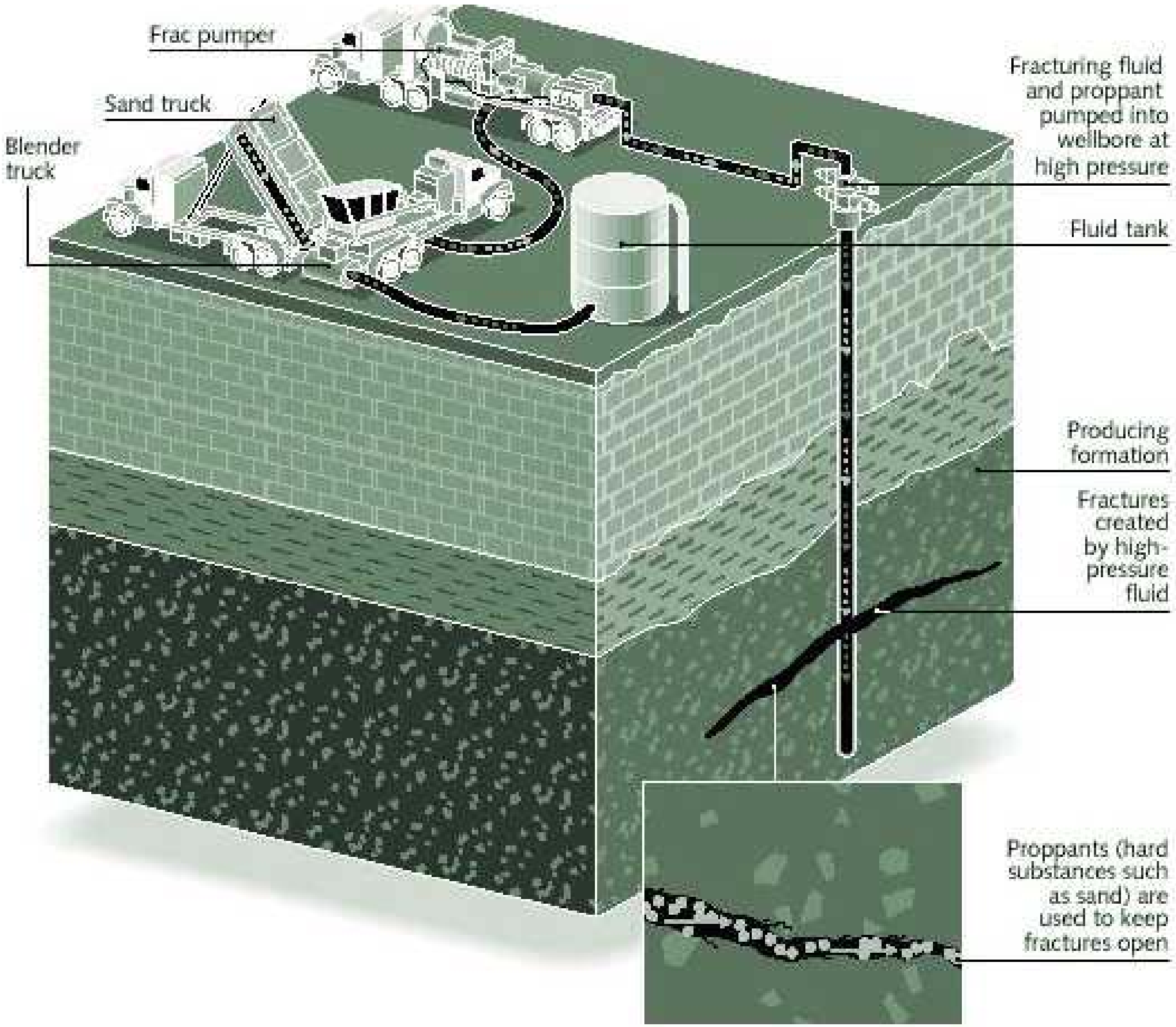
- Diversifies the sources of transportation energy and electricity energy
- Is relatively clean compared to coal and oil
- Is widely distributed throughout the U.S. via an existing pipeline network
- Can be used as a source of heat, power, electricity and transportation energy

An increase in low-cost U.S. natural gas reserves offers a range of opportunities to help the U.S. transition to a secure, low-cost, low-carbon energy future

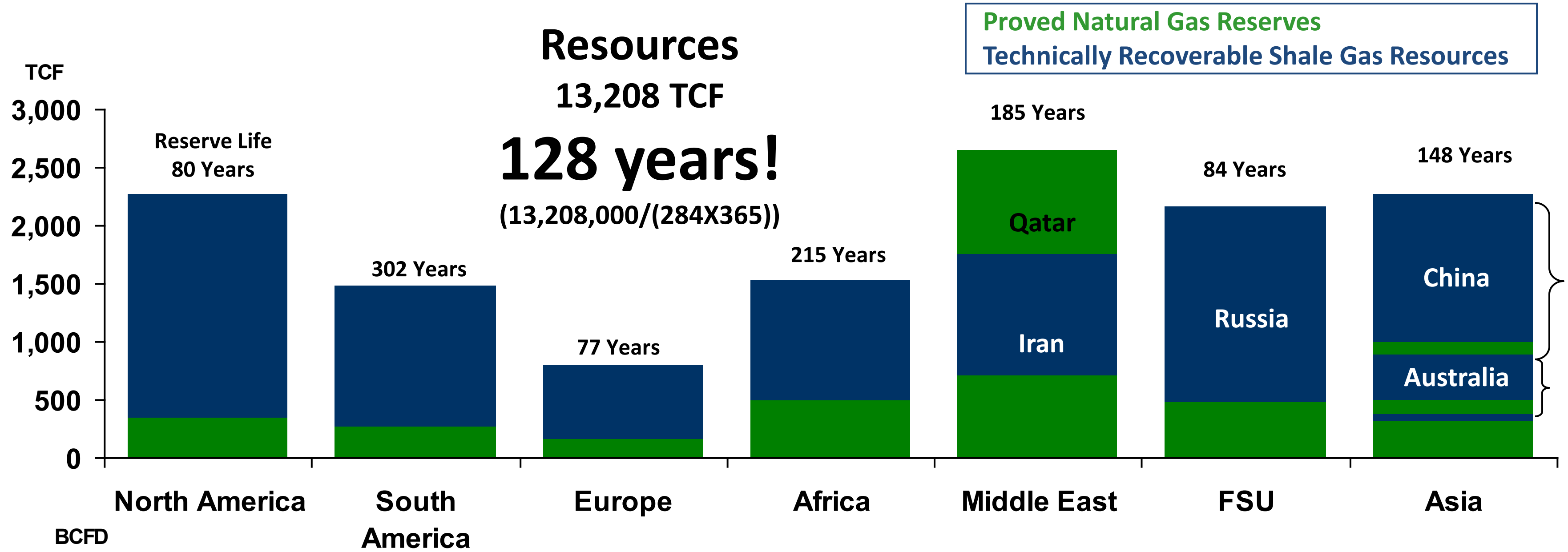
Key Drivers and Opportunities

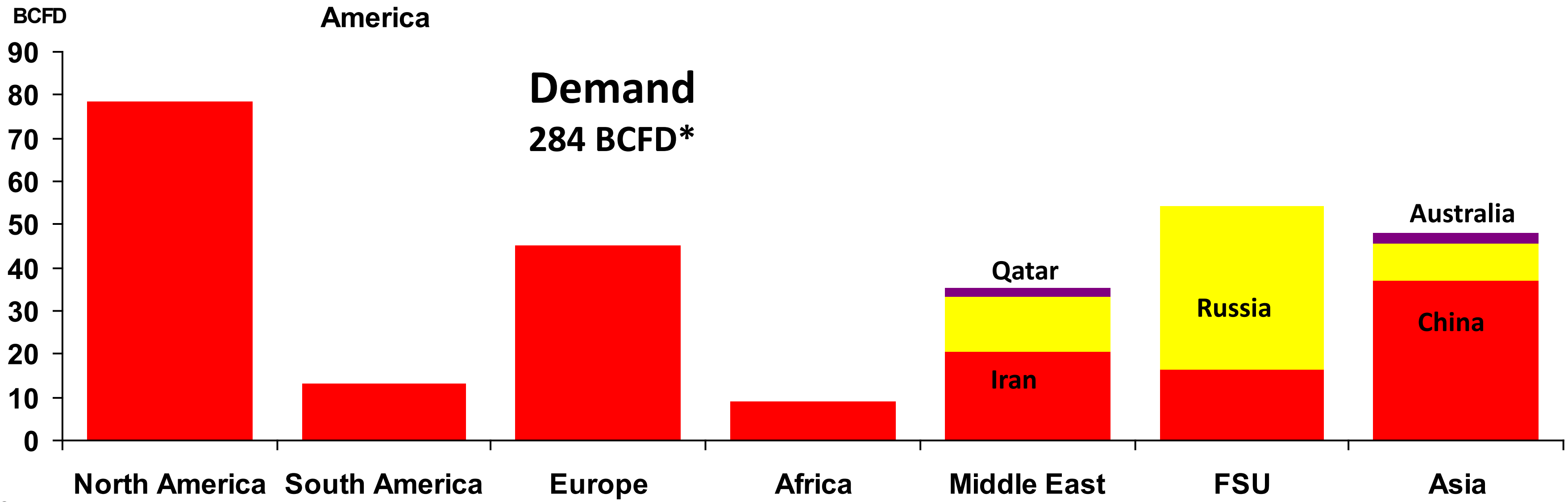


Hydraulic Fracturing



Proved Natural Gas Reserves And Technically Recoverable Shale Gas Resources



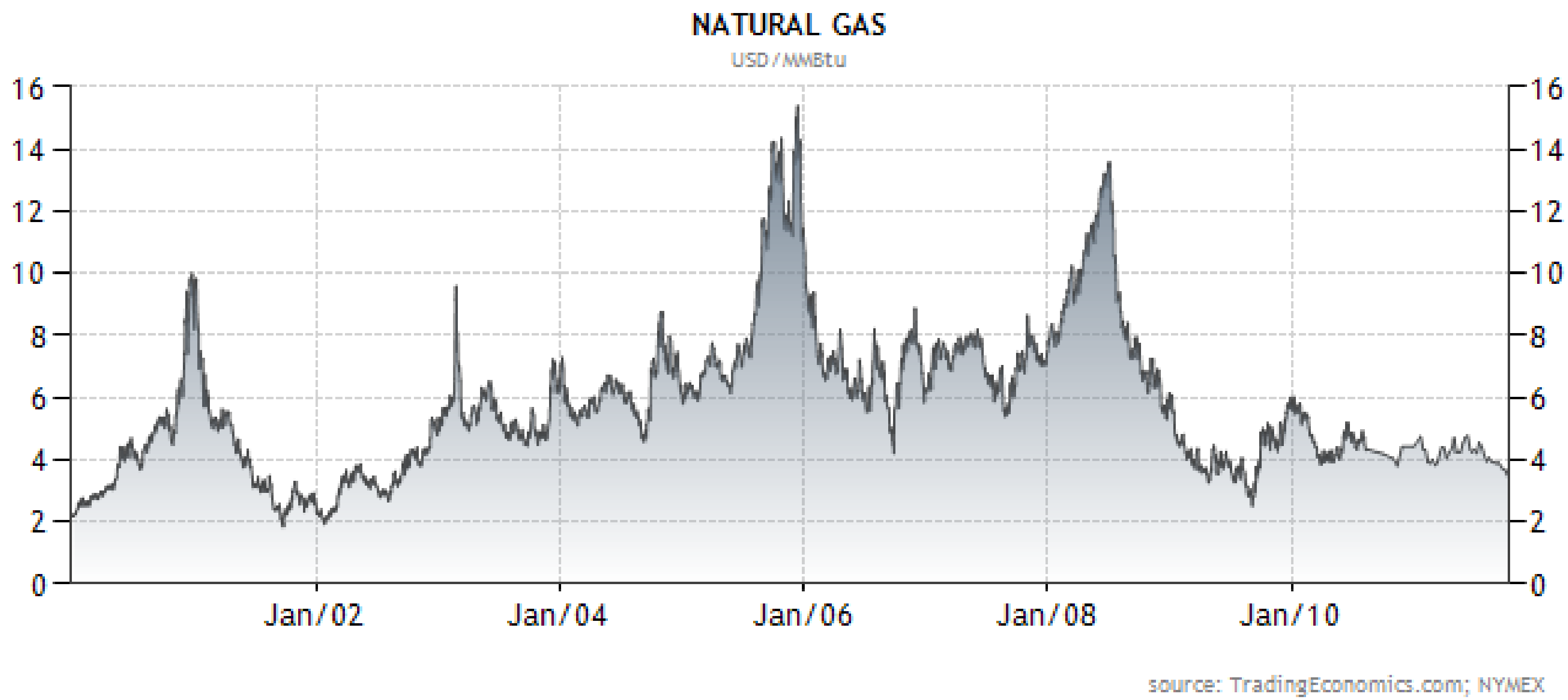


*2009

Source: BP Statistical Review, EIA 2010 Proved Reserves, World Shale Gas Resources Report, EIA 2011

Note: Unconventional reserves not available for Russia and Central Asia, Middle East, South East Asia, and Central Africa

Natural Gas Price



Shale Gas Risks

- Methane leakage into the atmosphere
  - One to three percent
  - Potent greenhouse gas
- Ground water contamination
  - Shale is typically found thousands of feet below the water table
  - If well casings fail, drilling fluids can seep into aquifers
- Surface water contamination
  - "Fracking" fluids return to the surface along with natural gas
  - Pollutants can find their way into surface water if not properly managed
- Propagation of shale fractures in unknown ways
  - Long-term impacts of shale fractures are not fully understood from a geological perspective

Key Questions

- How can the U.S. realize the greatest strategic value from shale gas relative to national security, economic growth, jobs growth, and environmental sustainability?

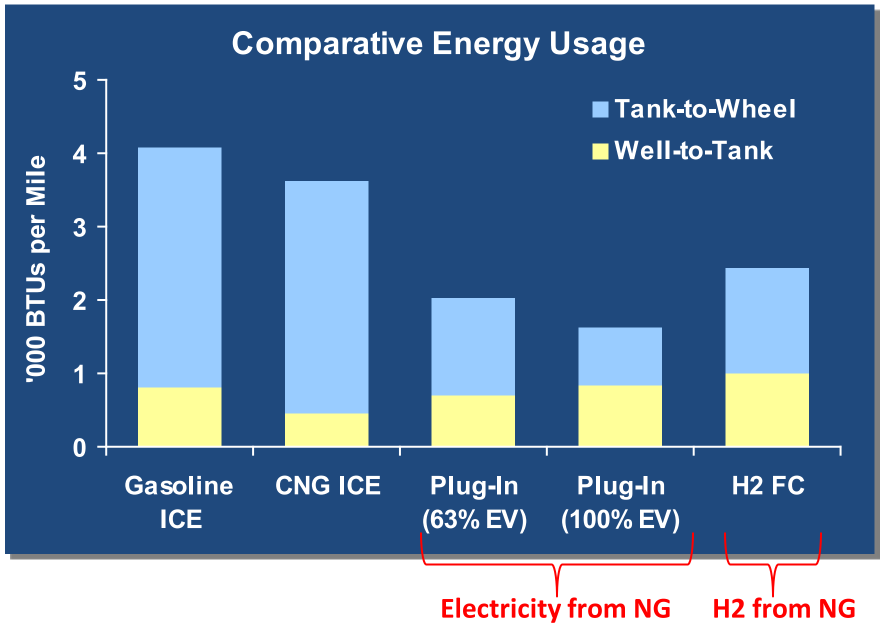
- How can the U.S. realize this strategic value <u>and</u> effectively manage the environmental risks of shale gas exploration and production?

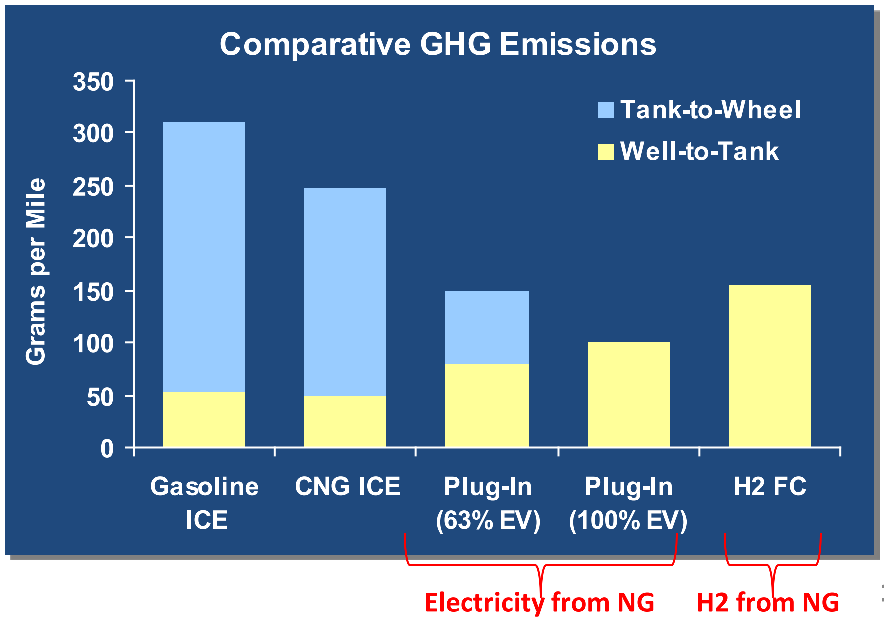
Natural Gas as a Light Duty Vehicle Energy Source

- **Three pathways**
  - **Compress → CNG → Combustion Vehicle**
  - **Burn → Electricity → Plug-In Electric Vehicle**
  - **Reform → Hydrogen → Fuel Cell Electric Vehicle**

- **CNG offers little efficiency/CO_2 advantage vs. gasoline**

- **Electricity and hydrogen pathways result in nearly twice the distance with half as much CO_2**





Natural Gas-to-Hydrogen for FCEVs

- Supply Chain Options
  - Reform natural gas at large scale (SMR) and compress/liquefy hydrogen for distribution by truck to stations which store and dispense
  - Pipe natural gas to stations and reform, compress, store and dispense hydrogen at station scale
  - Reform natural gas at medium/large scale and pipe hydrogen with natural gas to stations and separate/reform, compress, store and dispense at station scale
- Potential Economics
  - Several pathways appear to have the potential to compete with gasoline at $2-3 per gallon (non-taxed) assuming natural gas at $6 per MMBtu
  - Infrastructure investment to support first generation commercial FCEVs on order of 1/20th to 1/10th vehicle investment by five OEMs
    - 100-200 stations @ $1M-$2M per station
    - Five OEMs (Daimler, GM, Honda, Hyundai, Toyota) @ $1.0B-$1.5B each

Natural Gas as an Electricity Source

- Natural gas emits half as much CO_2 per unit of electricity as coal
- Many U.S. coal-fired power plants are reaching the end of their design lives
- A ”windfall” of low-cost natural gas from shale offers an opportunity to accelerate the retirement of these CO_2 intensive facilities

Analogy

- If your child won the lottery and you are responsible for determining what to do with her “windfall”, would you:
  - Squander it for immediate gratification?
  - Bury it in the backyard for fear something bad might happen if it is used?
  - Invest it wisely with effective risk management and appropriate balance between her near, mid and long-term (sustainable) benefits?
- Most responsible parents would opt to invest it wisely

Shale Gas “Windfall” Scenarios

- “Squander It”
  - Exploit “windfall” for near-term to mid- term economic gains
  - Produce gas with a “gold rush” fervor and use reserves as fast as economy demands
  - Economy would benefit from lower energy costs and jobs growth
  - Near-term political appeal is seductive and could result in sustainability and energy efficiency objectives taking a back seat

Shale Gas "Windfall" Scenarios

- "Squander It"
- "Bury It"
  - "Fracking" moratoriums and burdensome permitting requirements put the brakes on efforts to produce shale gas
  - "Windfall" adds little near-term to mid-term economic value or long-term strategic value due to concerns about environmental risks

Shale Gas “Windfall” Scenarios

- “Squander It”
- “Bury It”
- “Invest It”
  - Use “windfall” strategically to further U.S. objectives while ensuring effective environmental risk management
  - Strike the best balance between risk and return (like a financial portfolio)
  - Use “windfall” efficiently as part of an integrated energy system, and ensure maximum value is realized for a given level of risk

U.S. Strategic Implications of Shale Gas

- The U.S. must ensure its natural gas "windfall" from shale deposits is invested wisely
- This means realizing the greatest strategic value relative to
  - national security
  - economic growth
  - jobs growth
  - environmental sustainability
- It also means effectively managing the environmental risks of shale gas exploration and production
- The goal should be to use the new found gas to transition the U.S. to a secure, low-cost, low-carbon energy future

Specifically, the U.S. Should….

- Ensure shale gas is used to
  - Retire old coal power plants in the near-term
  - Supply CNG for economically viable commercial fleet applications
  - Supply electricity for plug-in EVs and hydrogen for fuel cell EVs
  - Develop integrated energy systems in concert with renewable energy (wind, solar and bio)
- Ensure shale gas is used efficiently to realize maximum economic value
- Ensure that the exploration and production of shale gas meets codes and standards that effectively manage the risks of “fracking”

In addition, the U.S. Should….

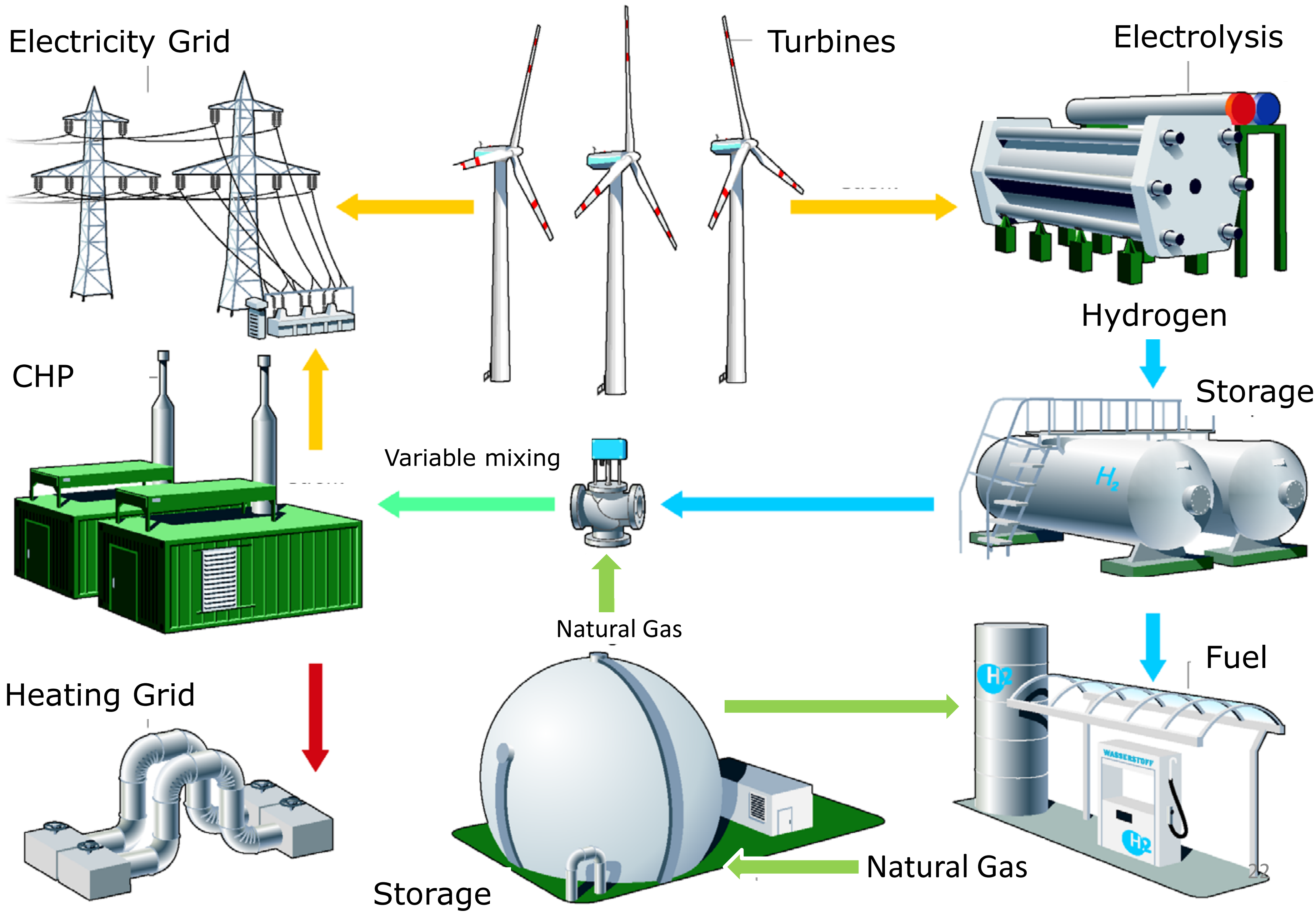
- Recognize that using shale gas to reduce oil imports ***could have significant strategic value***
  - Dependence on imported oil is problematic
  - Signaling a strong resolve to cut oil imports by using natural gas for transportation energy could reduce the influence of oil cartels and the trade-deficit from imported oil
  - Establishing the best near, mid and long-term portfolio of CNG, electricity and hydrogen applications is a balanced approach

Technology and Geo-Political Leverage

- Proven transformational <u>options</u> can impact geo-political dynamics prior to large scale transformation
- To show OPEC it has a viable and scalable option to importing oil, the United States should
  - deploy 10,000 electric vehicles (fuel cell and plug-in)
  - in one U.S. community
  - using plentiful U.S. natural gas & renewable energy as a source of hydrogen and electricity

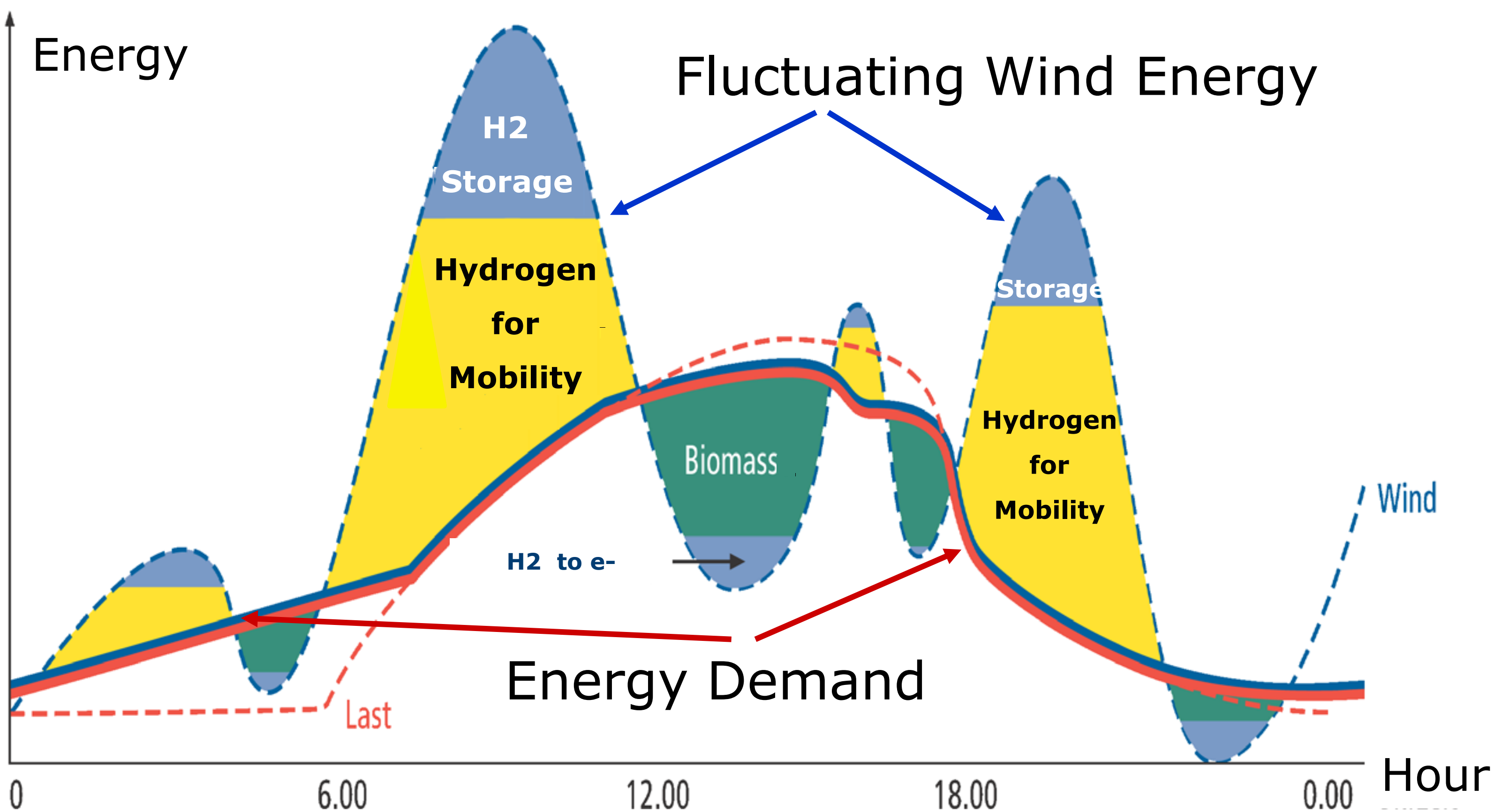
Integrated Energy System

(Source: Nationale Organisation Wasserstoff)



Integrated Energy System Opportunity

(Source: Nationale Organisation Wasserstoff)



Optimized Using Real-time Information on Energy Supply, Demand and Storage

Key Enablers

- Systems Engineering
- Real-Time Information and Control
- Optimized Energy Storage

Energy Storage: Infrastructure

- Surplus wind and solar energy can be used to generate electricity to
  - ✓ pump water into elevated reservoirs
    - low energy storage density and efficiency
    - does not apply widely
  - ✓ compress air into underground caverns or tanks
    - low energy storage density and efficiency
  - ✓ recharge advanced batteries
    - low energy storage densities
    - requires further technology breakthroughs
  - ✓ ***electrolyze water to create hydrogen and***
    - ***compress it into underground caverns or tanks***
      - ✓ ***relatively high energy density***
      - ✓ ***unproven "round-trip" economic viability***
    - ***mix it in natural gas pipelines and separate/reform at stations***
      - ✓ ***10-20% mix potential***
      - ✓ ***significant storage capacity***

DOE Role

- Provide objective, fact based analysis and information on how much shale gas exists in the U.S., where it exists and how exploration and production risks vary by location
- Assess the near, mid and long-term implications of shale gas supply relative to the overall U.S. energy portfolio
- Work with EPA, States and energy industry to ensure effective risk management of shale gas exploration and production
- Assess natural gas supply infrastructure “bottlenecks” to better prepare the U.S. to make use of shale gas in electricity, power, heat and transportation applications
- Work with DOC and DOL to assess jobs implications in the natural gas, coal, oil and renewable energy industries
- Conceive, model and analyze integrated energy systems to fully comprehend the synergies between natural gas and renewable energy
- Ensure the U.S. “stays the course” with a broad portfolio of energy supply and use technology given that long-term shale gas supply is likely exhaustible
- Fund natural gas-to-hydrogen transportation infrastructure demonstration programs in collaboration with industry and States

Summary

- Appears “fracking” has created abundant U.S. reserves of low-cost natural gas
- U.S. should invest this “windfall” wisely to address multiple strategic objectives
  - National security
  - Economic growth
  - Jobs growth
  - Environmental sustainability
- Using shale gas to reduce oil imports could have significant strategic value
- Shale gas should be used efficiently to realize maximum economic value
- Shale gas should be used to
  - Retire old coal power plants in the near term
  - Supply CNG for economically viable commercial fleet applications
  - Supply electricity for plug-in and hydrogen for fuel cell EVs
  - Develop integrated energy systems in concert with renewable energy
- Exploration and production of shale gas must meet codes and standards that effectively manage the risks associated with “fracking”

Back-Ups

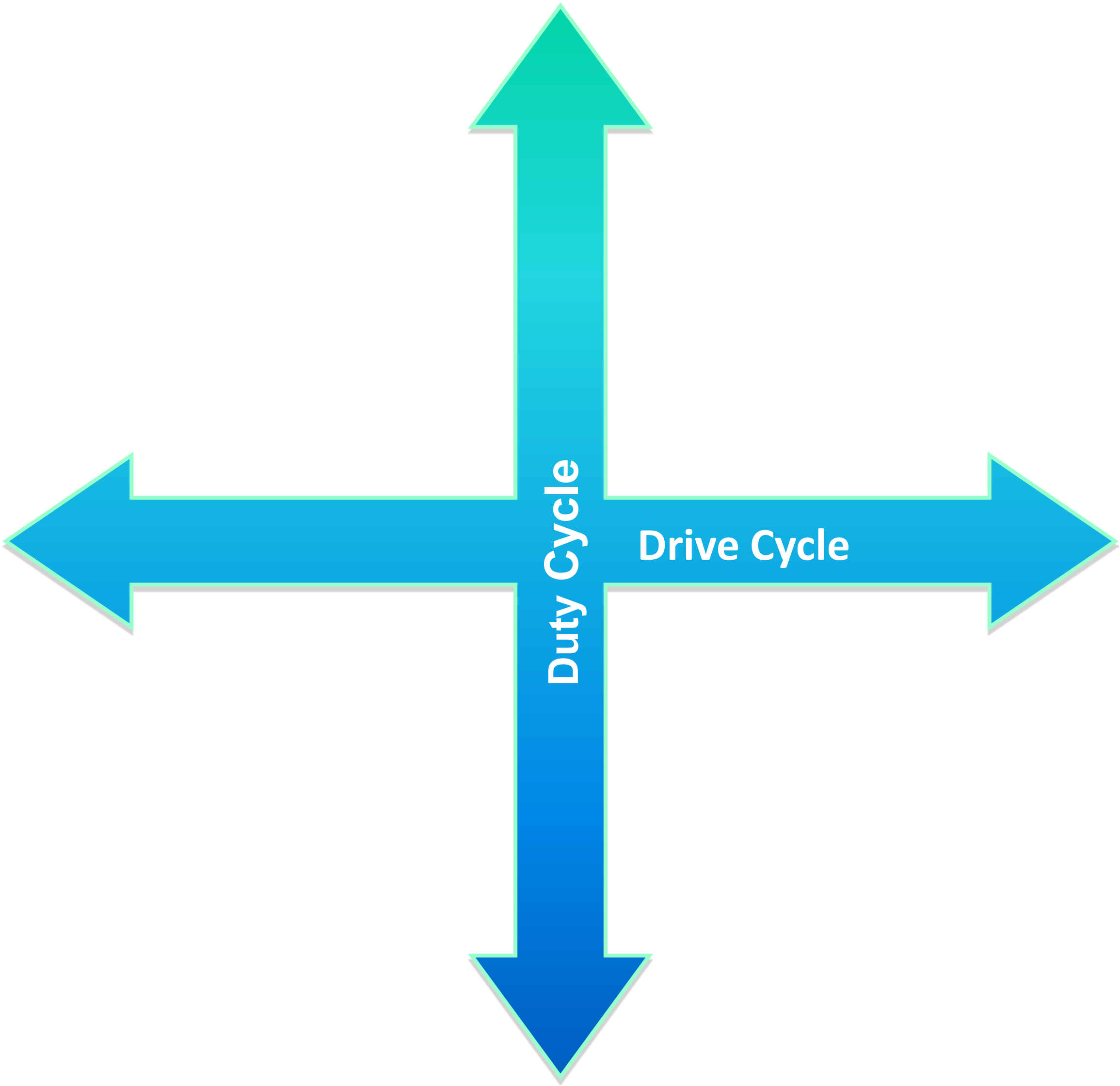
STRATEGIC IMPLICATIONS FOR RENEWABLE ENERGY

- “Squander It” Scenario
  - appetite for renewable energy will likely wane
  - renewable energy R&D budgets and market subsidies will likely decline
- “Bury It” Scenario
  - renewable energy will be positioned by environmental leaders as the cleaner and lower risk alternative to shale gas
  - ongoing debate regarding the future of U.S shale gas will add uncertainty to renewable energy investments
- “Invest It” Scenario
  - market “tipping point” cost targets for wind, solar, bio and geothermal energy will be reduced given added supply of low-cost natural gas
  - synergies between natural gas and renewable energy will be leveraged as part of integrated energy systems

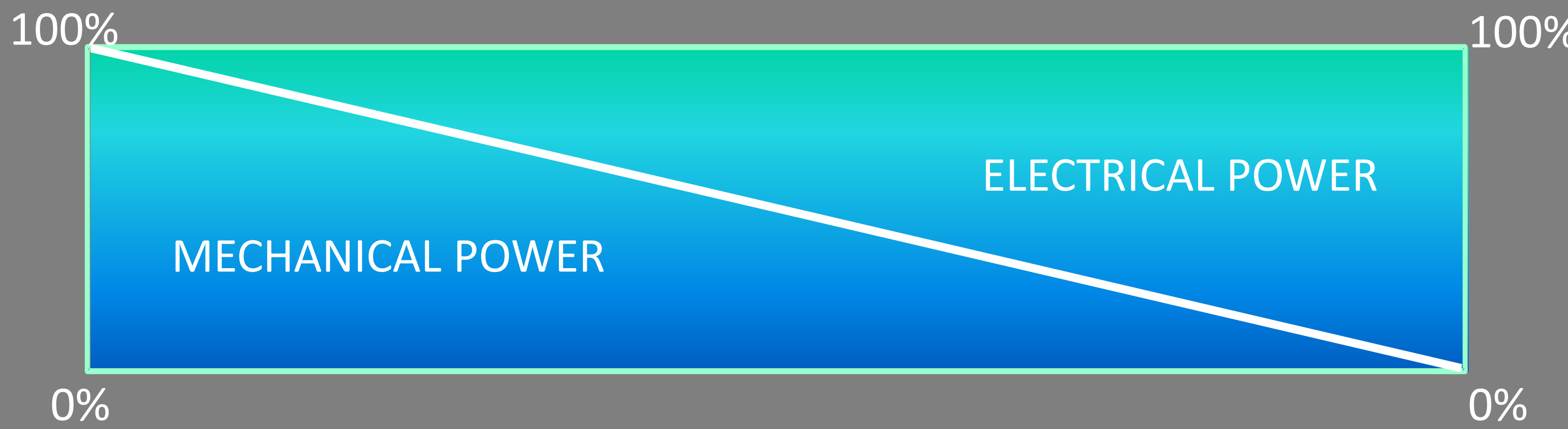
New Technology “Improves” Existing Technology

- Aluminum is driving improvements in steel auto bodies
- Electric vehicles are driving improvements in internal combustion engines
- Plentiful natural gas will drive improvements in coal and renewables

Range of Consumer Needs

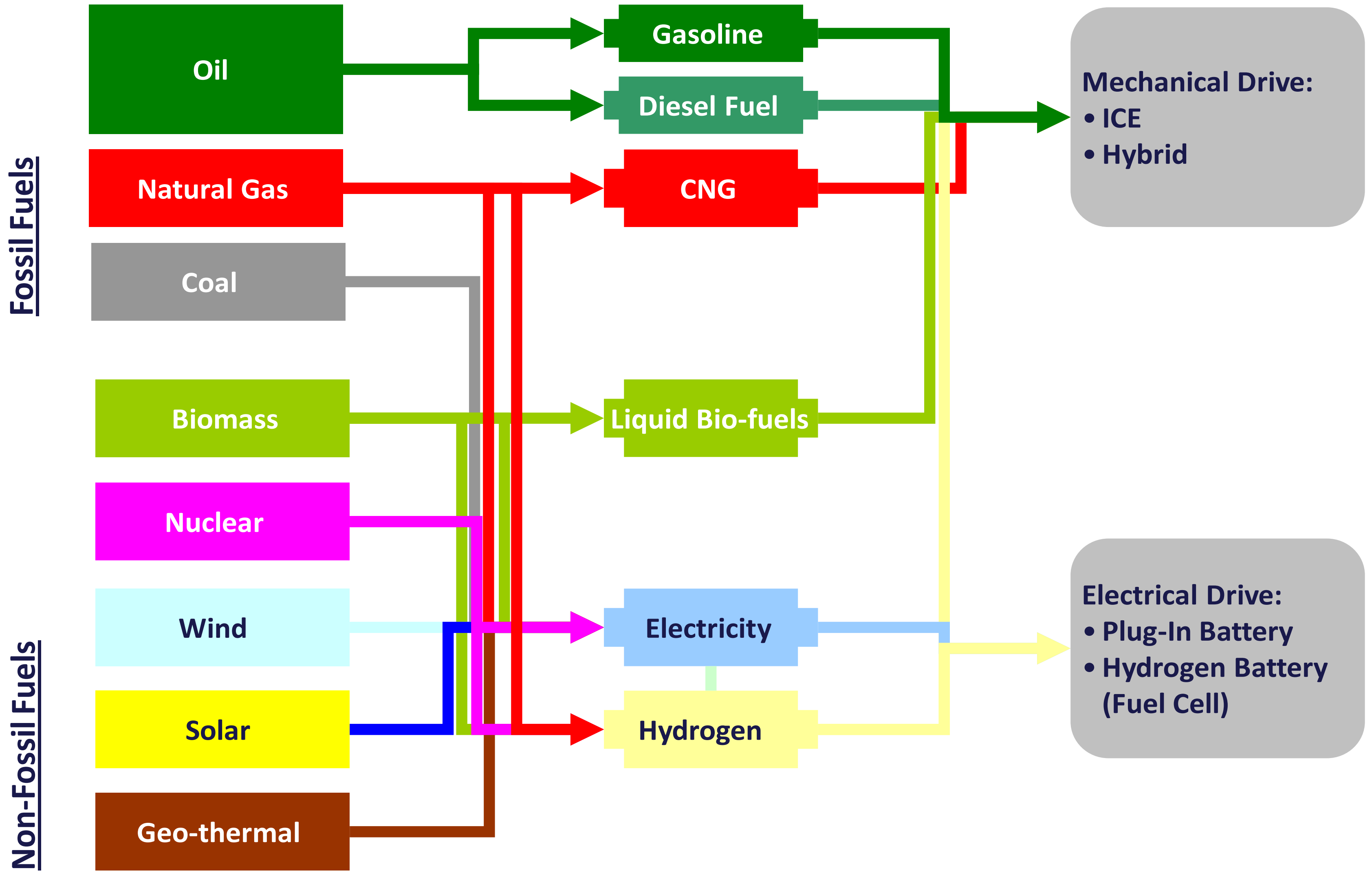


Vehicle Electrification



Internal Combustion Engine (ICE)	Hybrid (HEV)	PlugIn Hybrid (PHEV)	Extended Range Electric (EREV)	Battery Electric (BEV) Fuel Cell Electric (FCEV)
Mechanical Drive	Mechanical Drive with Electrical Assist		Electrical Drive with Mechanical Assist	Electrical Drive

Road Transportation Energy Supply

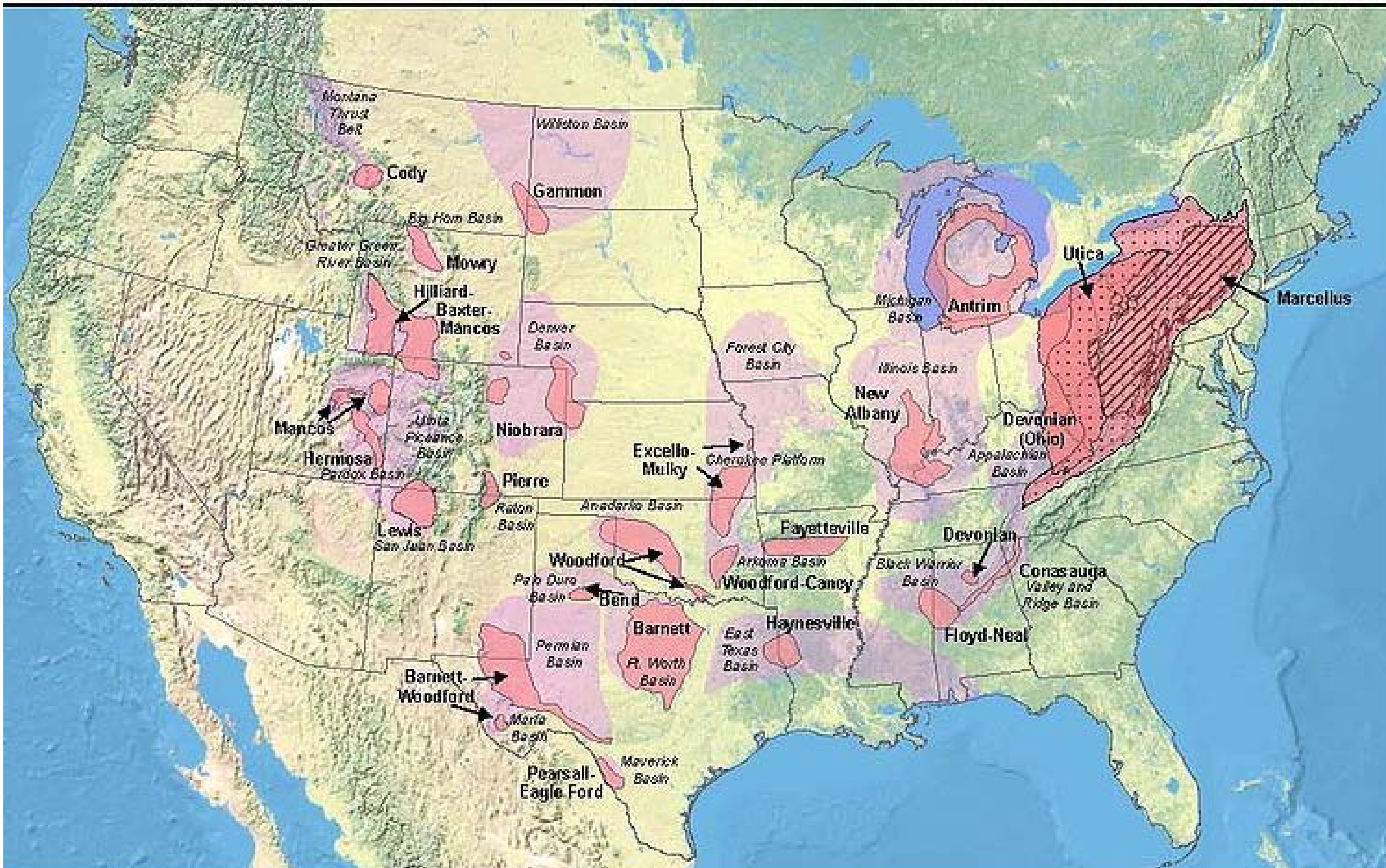


Energy Diversity Challenge

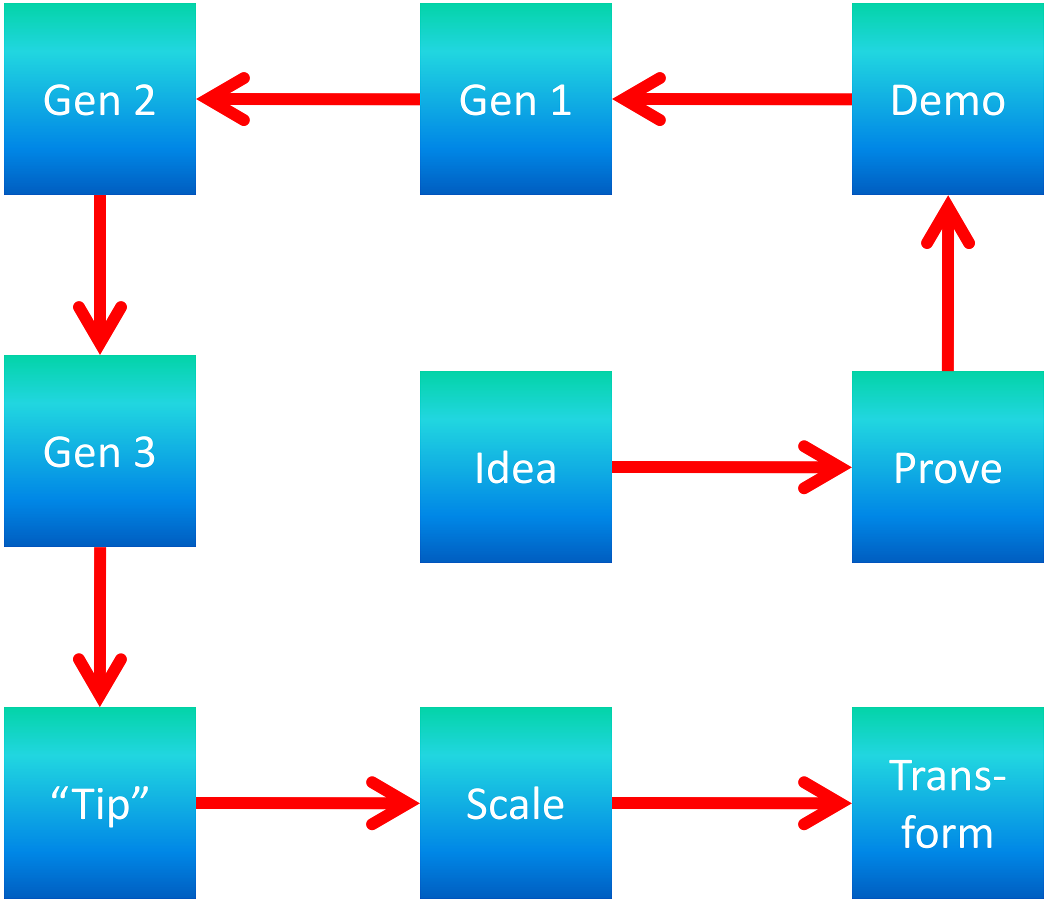
- Not a question of invention or know-how

- A "chicken and egg" challenge
  - Co-dependence of vehicles and energy supply
- An economic challenge
  - Capital required for infrastructure
  - Produce alternatives at competitive costs

Natural Gas from Shale Deposits



Learning is Key to Transformational Change



Learn about technology, customers and supply processes