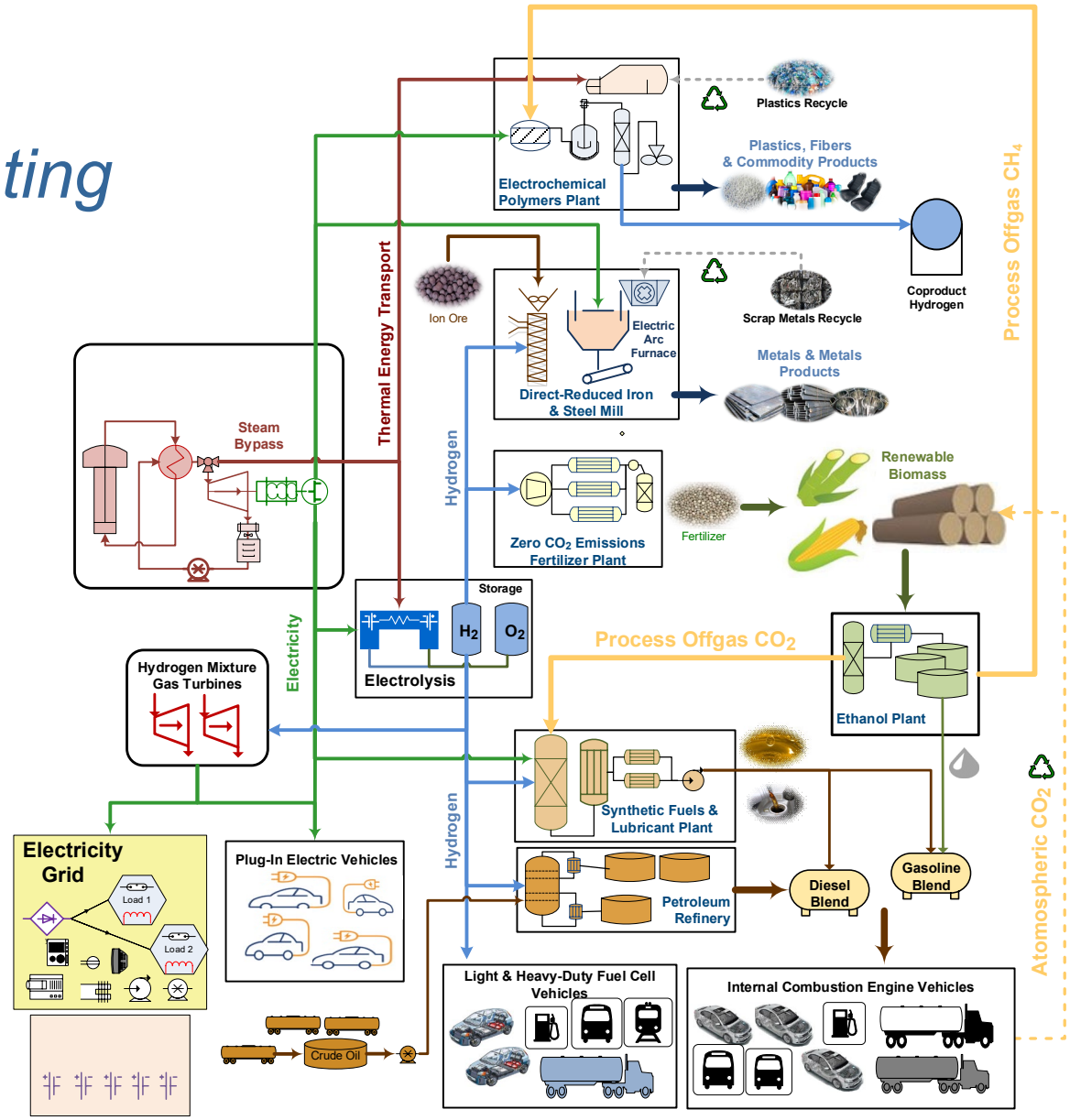
Industry Energy Hubs with Integrated Energy Systems

University of Toledo Meeting

Richard Boardman, Ph.D.
Lead, DOE Light-Water Reactor
Integrated Energy Systems Pathway

January 14, 2020



www.inl.gov

Idaho National Laboratory

Current Energy Sector Systems and Services

Resource Production and Delivery

- ❑ Fossil fuels production, transportation and refining
- ❑ Power generation, transmission/distribution
- ❑ Primary metals production and refining
- ❑ Minerals production and processing
  - soda, phosphate
  - precious, rare earth
- ❑ Foresting / wood products milling and pulp production
- ❑ Feedstock chemicals manufacturing
- ❑ Glass making
- ❑ Cement and masonry production
- ❑ Biomass refuse and MSW management
- ❑ Water production and treatment

Conversion and Manufacturing Industries

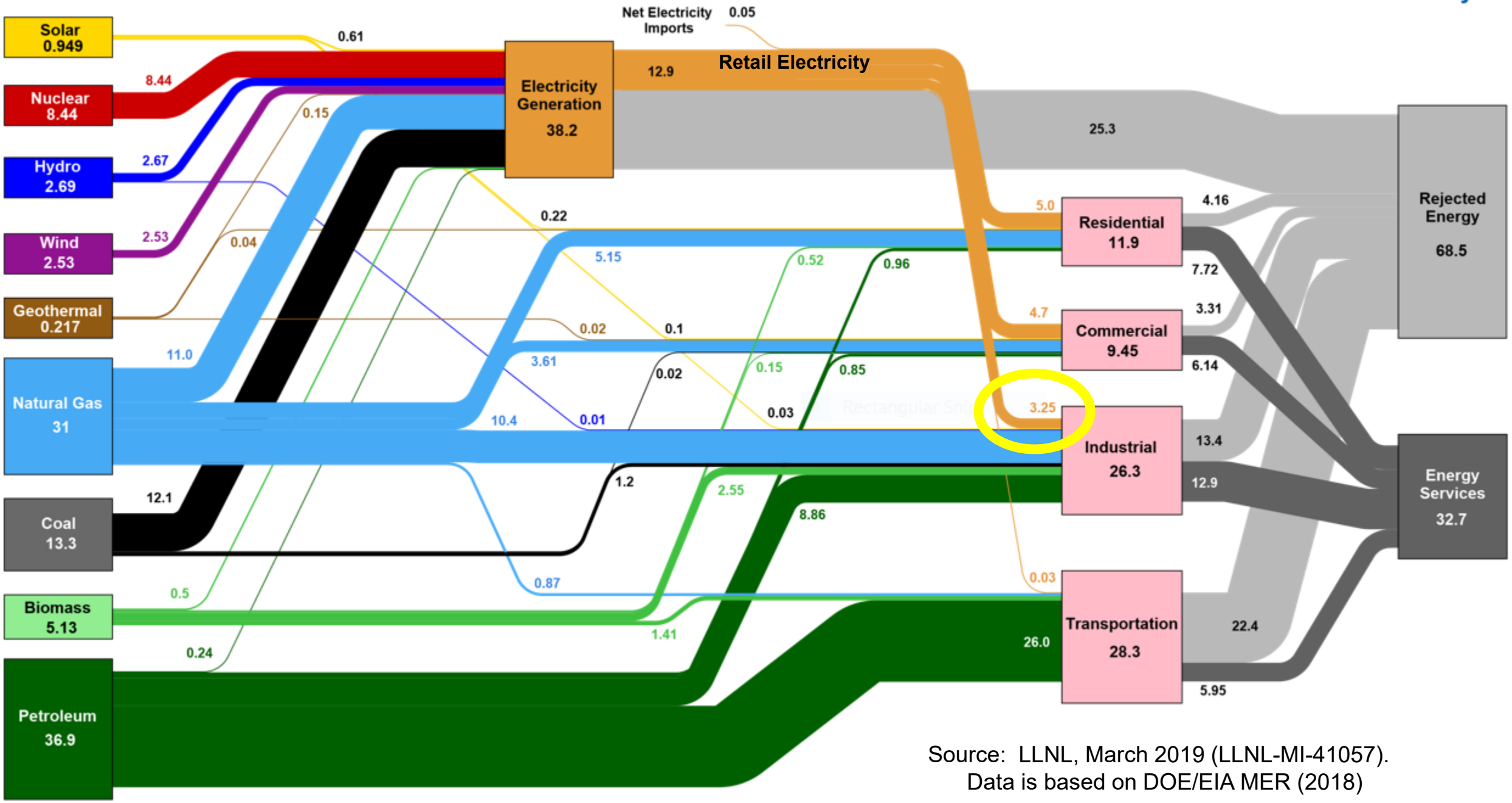
- ■ Ammonia & fertilizers production
- ■ Agriculture and ranching
- ■ Food processing
- ■ Chemicals utilization:
  - polymers, plastics, resins, composites
  - Natural and synthetic textiles
  - synthetic rubber
- ■ Automotive manufacturing
- ■ Steel rolling, casting, and milling
- ■ Paper and paperboard production
- ■ Electronics fabrication and assembly
- ■ Potable water purification
- ■ Biodiesel and ethanol fuels

Consumer Services

- ✓ Nourishment
- ✓ Water
- ✓ Clothing apparel
- ✓ Shelter and furniture
- ✓ Transportation
- ✓ Infrastructure
- ✓ Lighting
- ✓ Comfort (heating and air conditioning)
- ✓ Communications, computing & data storage
- ✓ Medical supplies & pharmaceuticals
- ✓ Entertainment

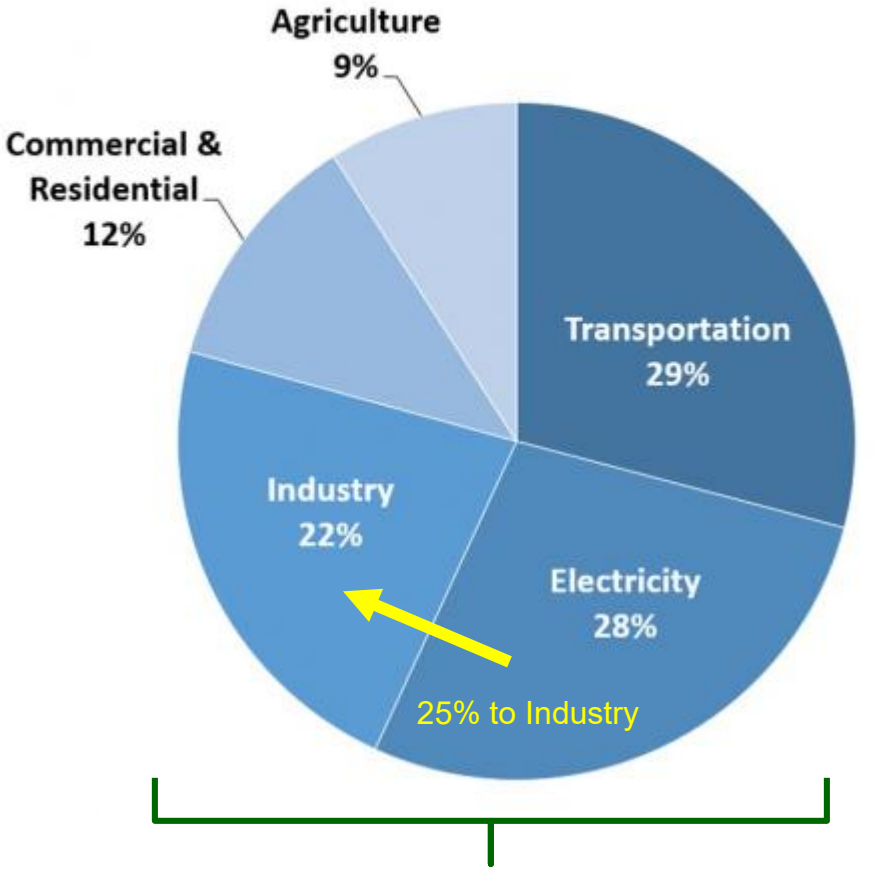
Estimated U.S. Energy Consumption in 2018: 101.2 Quads

Lawrence Livermore National Laboratory



Source: LLNL, March 2019 (LLNL-MI-41057).
Data is based on DOE/EIA MER (2018)

Total U.S. Greenhouse Gas Emissions by Economic Sector in 2017



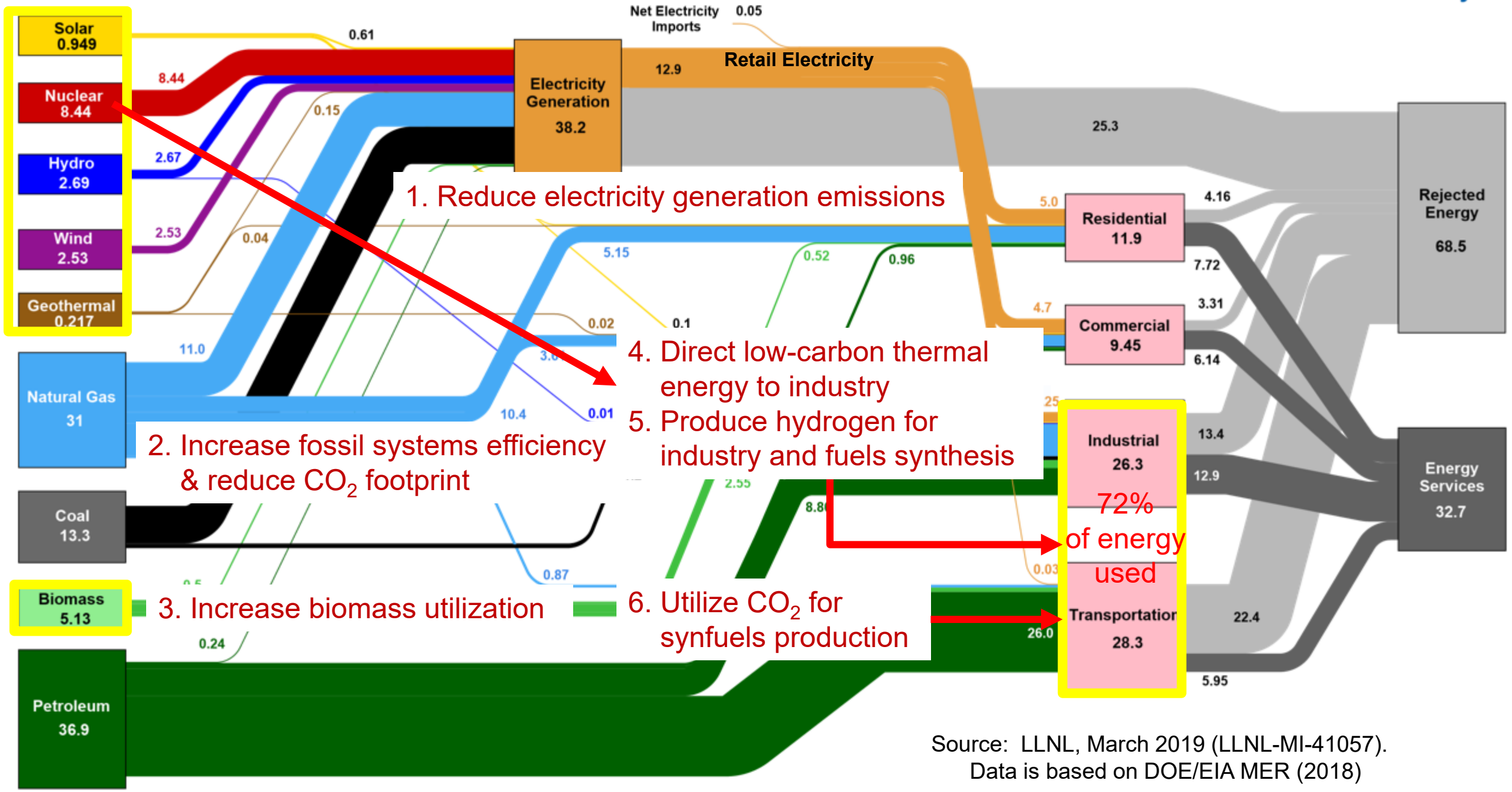
Land use 11.1% offset in 2017 through adsorbed CO_2

- Transportation (28.9 percent of 2017 greenhouse gas emissions) – The transportation sector generates the largest share of greenhouse gas emissions. Greenhouse gas emissions from transportation primarily come from burning fossil fuel for our cars, trucks, ships, trains, and planes. Over 90 percent of the fuel used for transportation is petroleum based, which includes primarily gasoline and diesel.[2]
- Electricity production (27.5 percent of 2017 greenhouse gas emissions) – Electricity production generates the second largest share of greenhouse gas emissions. Approximately 62.9 percent of our electricity comes from burning fossil fuels, mostly coal and natural gas. 25% of retail electricity is sent to industry.
- Industry (22.2 percent of 2017 greenhouse gas emissions) – Greenhouse gas emissions from industry primarily come from burning fossil fuels for energy, as well as greenhouse gas emissions from certain chemical reactions necessary to produce goods from raw materials.
- Commercial and Residential (11.6 percent of 2017 greenhouse gas emissions) – Greenhouse gas emissions from businesses and homes arise primarily from fossil fuels burned for heat, the use of certain products that contain greenhouse gases, and the handling of waste.
- Agriculture (9.0 percent of 2017 greenhouse gas emissions) – Greenhouse gas emissions from agriculture come from livestock such as cows, agricultural soils, and rice production.
- Land Use and Forestry (offset of 11.1 percent of 2017 greenhouse gas emissions) – Land areas can act as a sink (absorbing CO_2 from the atmosphere) or a source of greenhouse gas emissions. In the United States, since 1990, managed forests and other lands have absorbed more CO_2 from the atmosphere than they emit.

Estimated U.S. Energy Consumption in 2018: 101.2 Quads

Lawrence Livermore National Laboratory

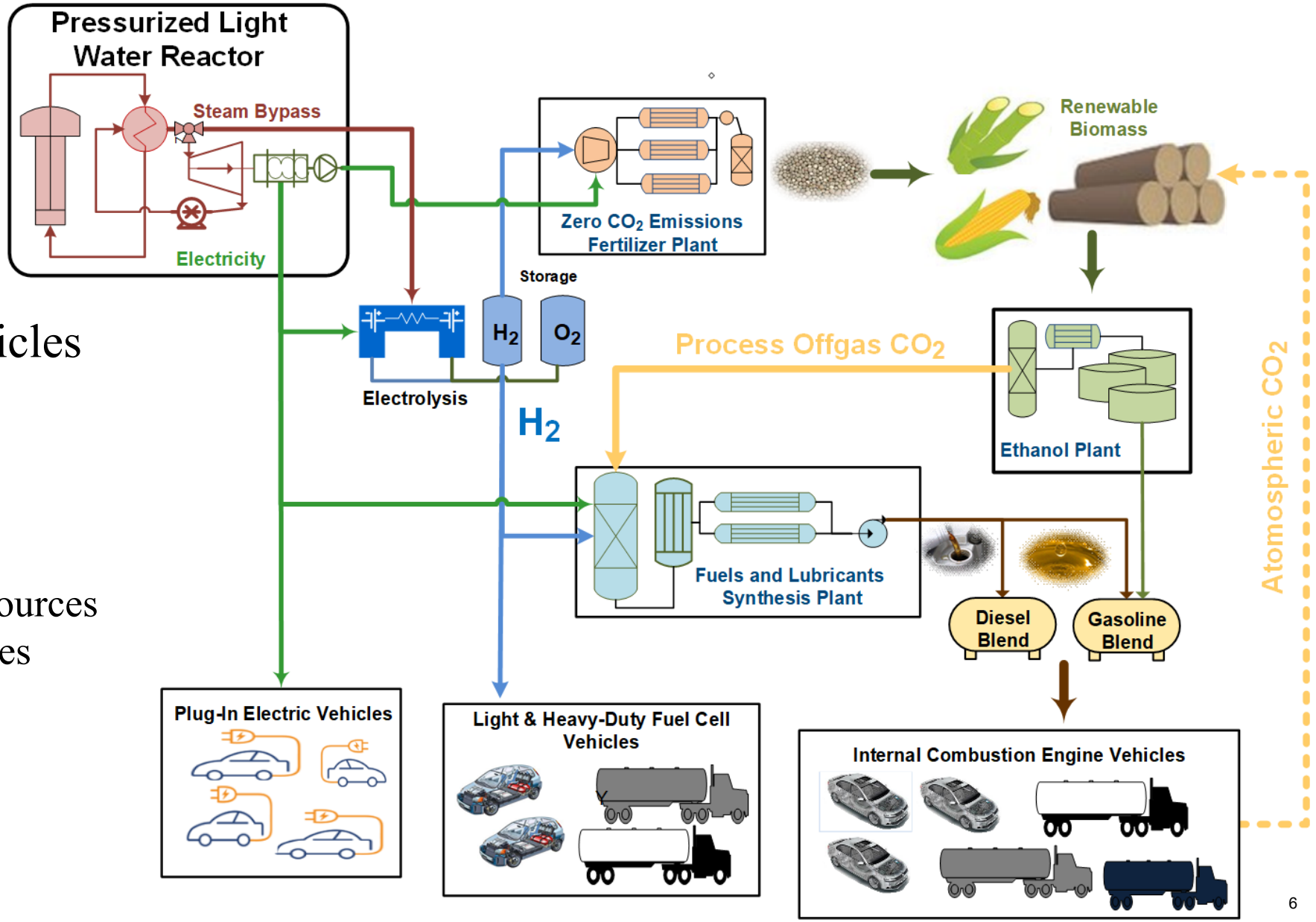
20%: non-fossil



Source: LLNL, March 2019 (LLNL-MI-41057).
Data is based on DOE/EIA MER (2018)

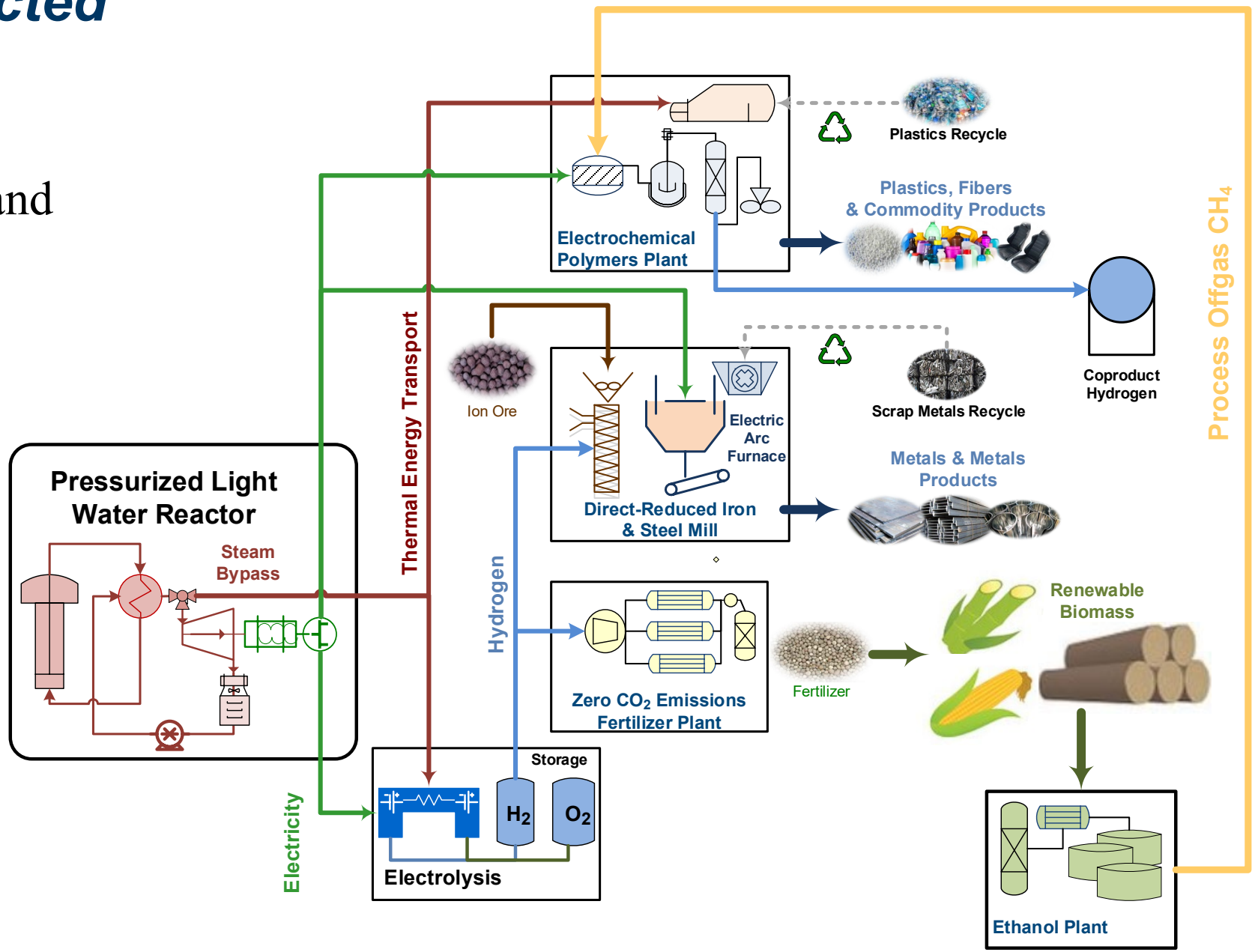
Nuclear-powered cars and trucks

A. Electric Vehicles
B. Hydrogen Fuel Cell Vehicles
C. Biofuels (i.e. ethanol)
   - » low carbon fertilizers
D. Synthetic Hydrocarbons
   - » diesel and gasoline
   - » emissions-free energy sources
   - » renewable carbon sources



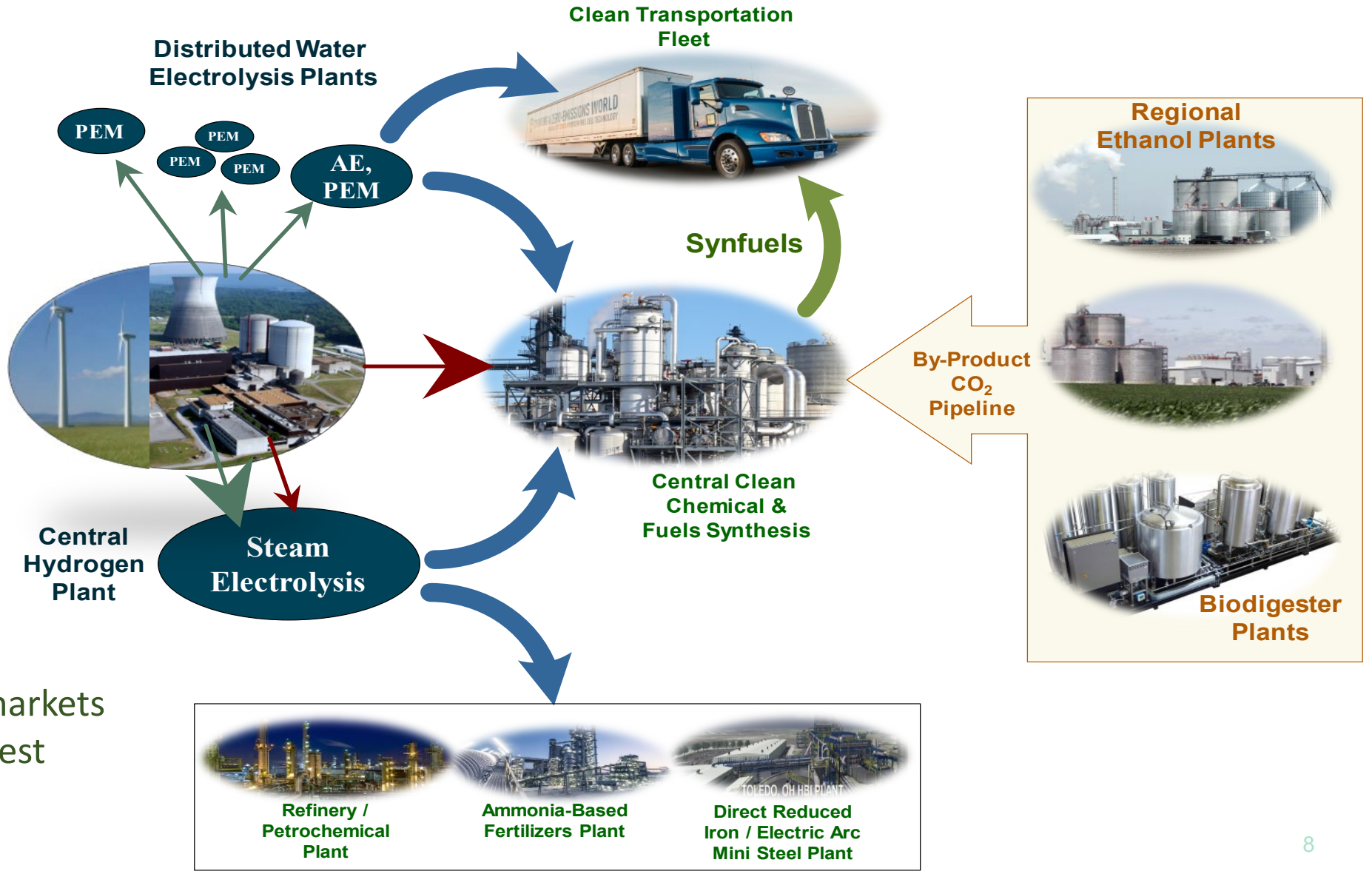
Nuclear energy directed to industry

A. Directed reduced iron and electric arc furnaces
B. Fertilizer production
C. Polymers production
D. Plastics recycle



Toledo Area Energy Hub

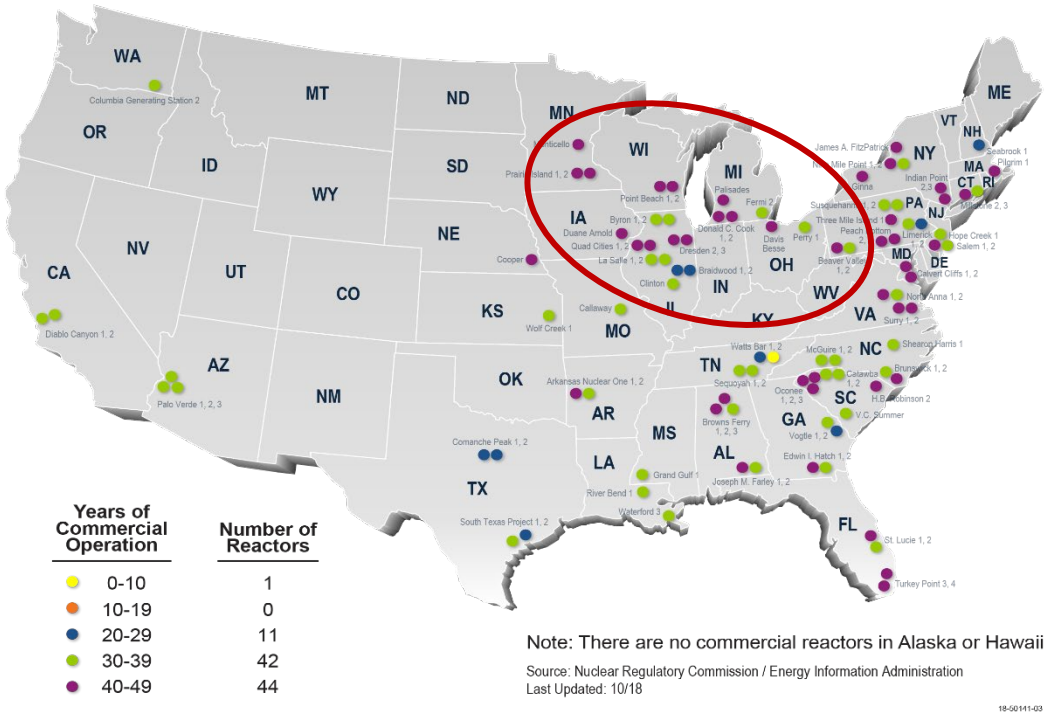
- ❑ Fundamental R&D with University
- ❑ Technology development and acceleration
- ❑ DOE Cost-Share Demonstrations



Evaluation of Non-electrical markets for a Light-Water in the Midwest
INL, NREL PNNL, ANL, SNL

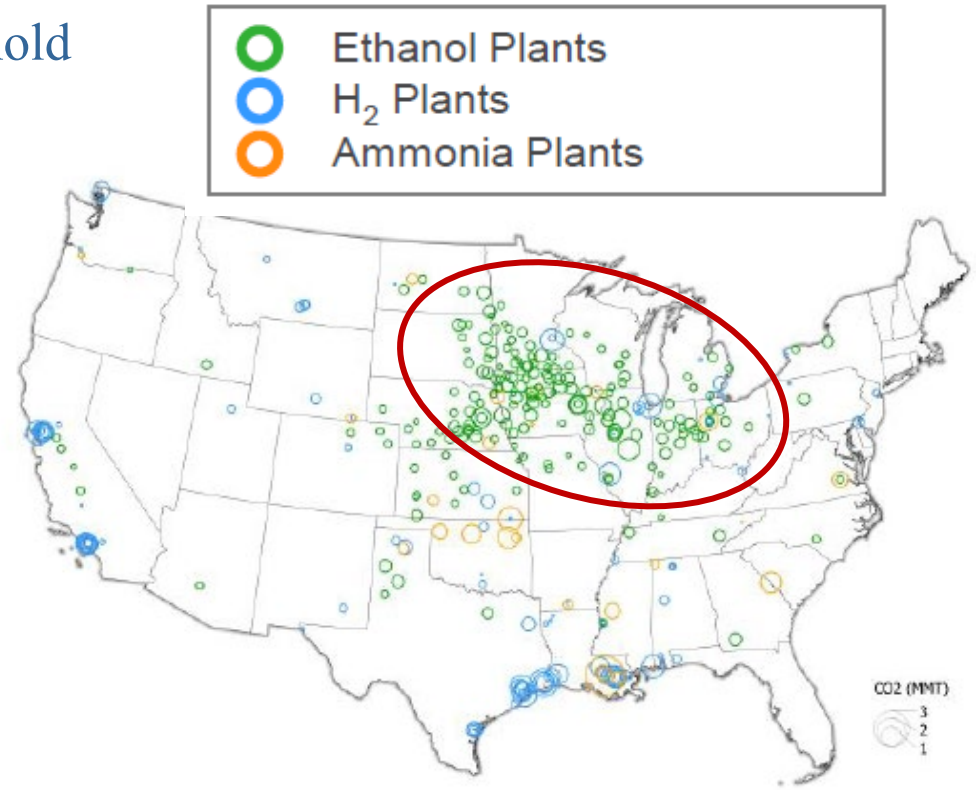
3. Large commercial markets that are relative inelastic

- » Transportation sector inertia continues remains strong
- » Fossil fuels costs are presently near a minimum threshold



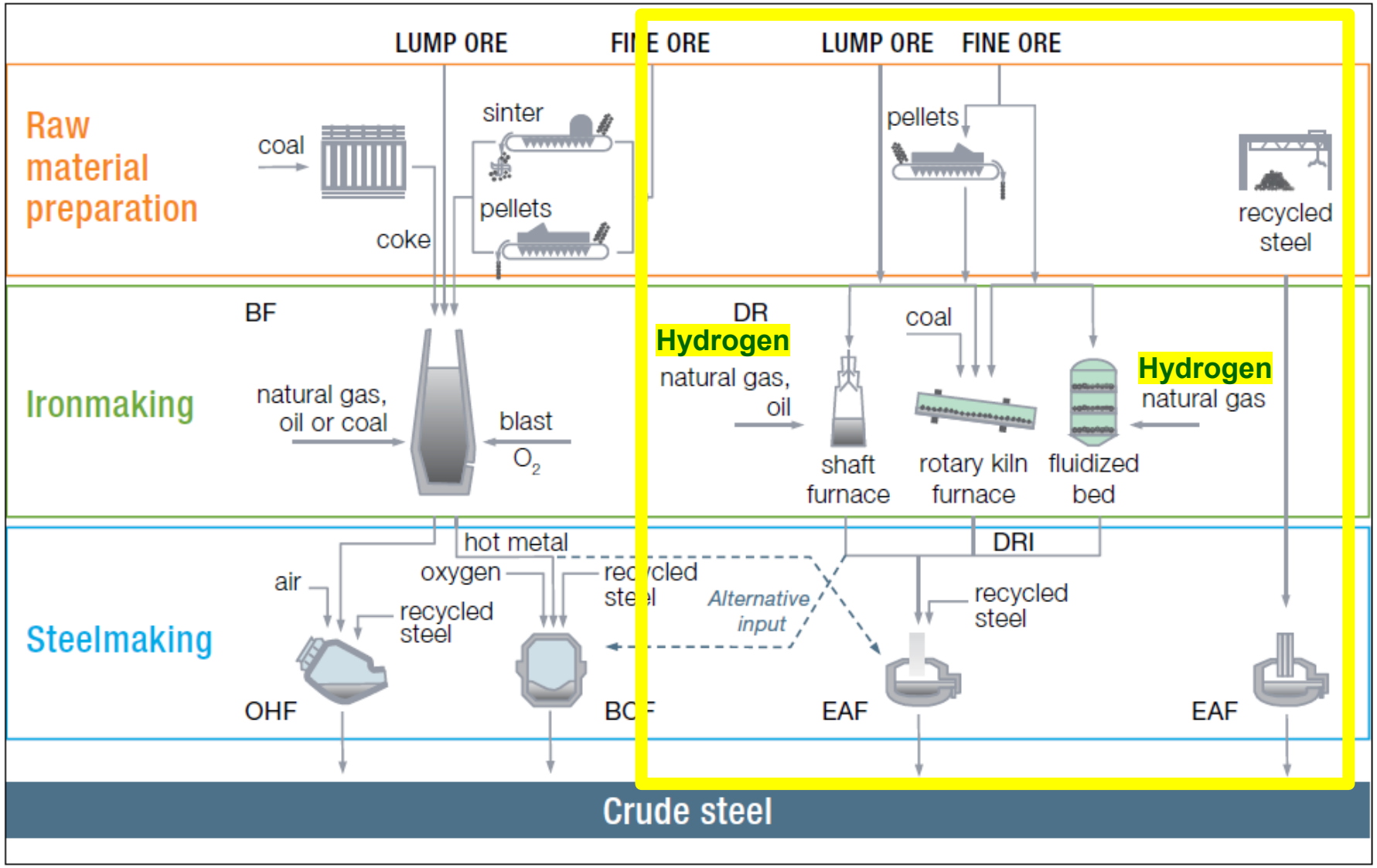
- ❑ Distribution of 98 operating nuclear power plants in the U.S.
  - » 17 Reactors in the zone of ethanol plants
  - » 3-4 MMT of H_2 hydrogen production potential

S. D. Supekar, S. J. Skerlos, *Environmental Science & Technology*. **48**, 14615–14623 (2014).



- ❑ 44 MMT of CO_2 from ethanol plants
  - » 4.7 Billion gallons for F-T Fuels
  - » 6 MMT of H_2 potential demand for fuels synthesis
  - » 0.5 MMT of H_2 for fertilizer for crops

Steel Making Routes

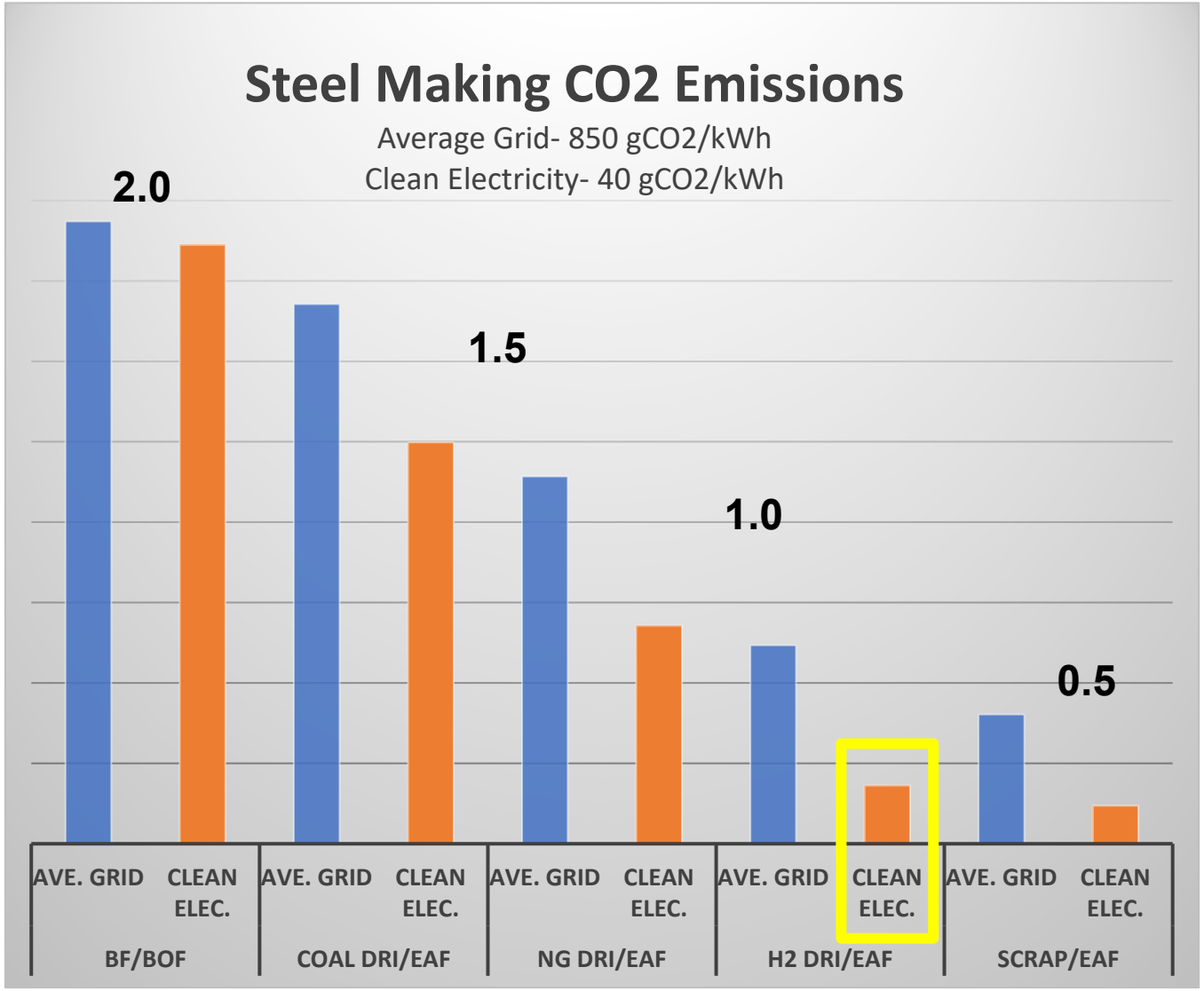


- 75% of steel making today is by the BF-BOF route
- 25% of world steel is produced by EAF using scrap or DRI iron

- ✓ Coal, oil, and natural gas can be substituted with hydrogen for DRI production
- ✓ Clean electricity can be used to power EAF and other operations

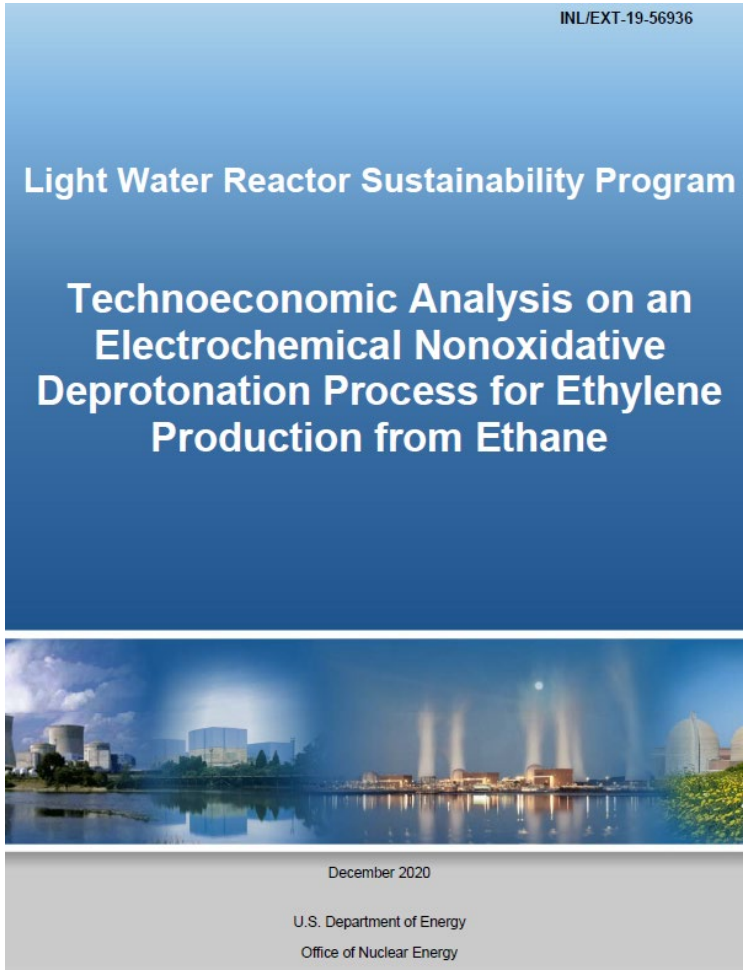
Graphic Source: World Steel Association Fact Sheet: Energy Use in the Steel Industry

Steel Making Options CO_2 Emissions Comparison

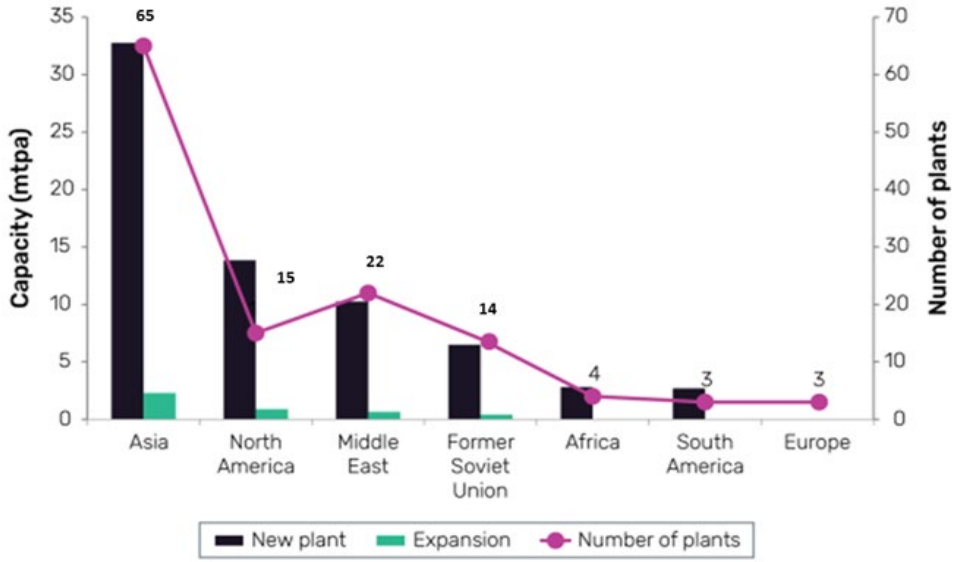


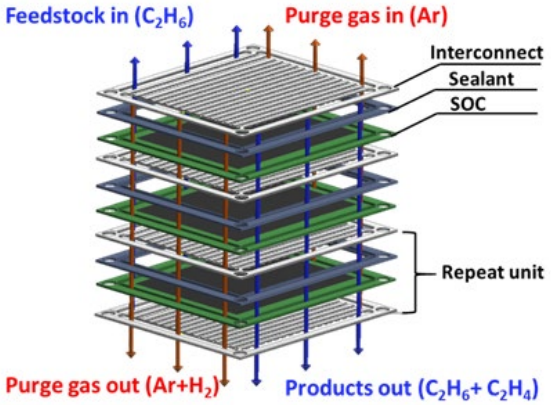
Low-emissions electricity and hydrogen from electrolysis yield 50-90% reduction in CO_2 emissions for finished steel products

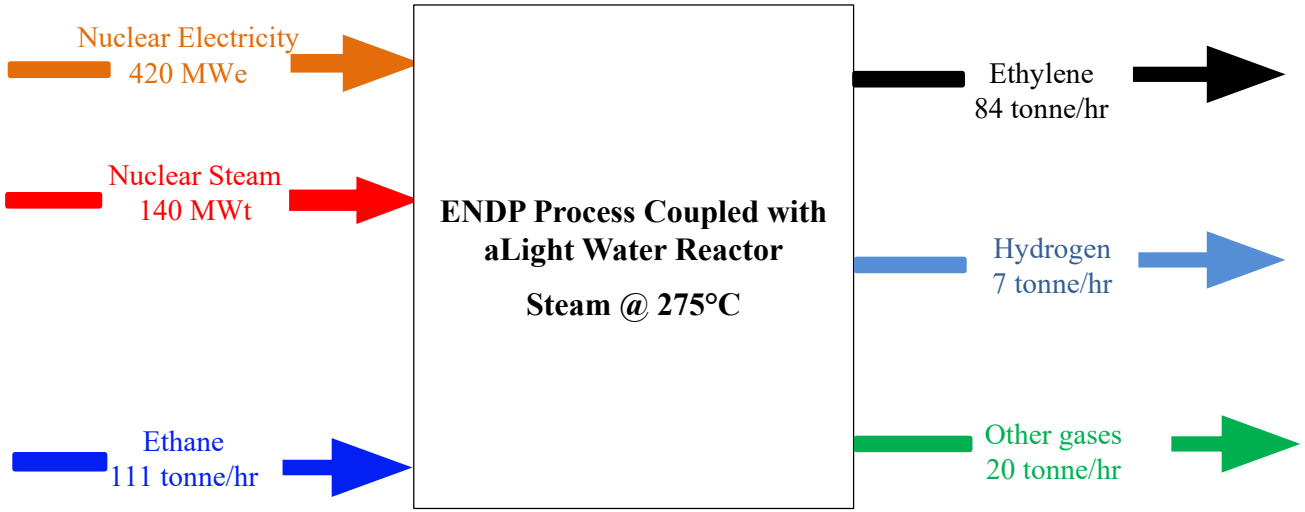
Converting Natural Gas Condensates into Polymers with Nuclear Energy

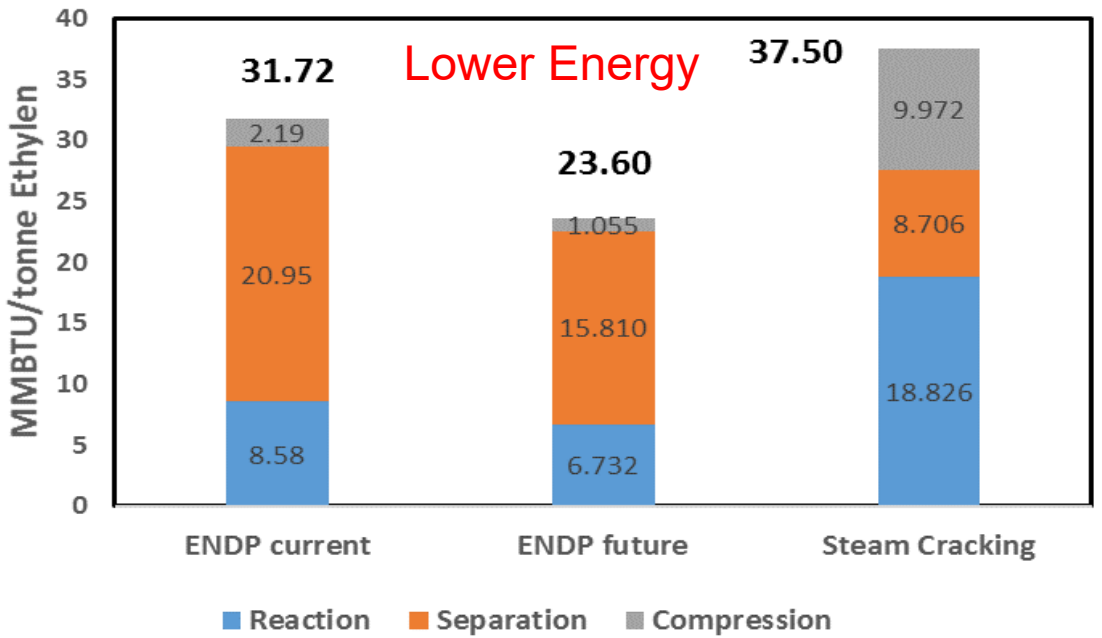


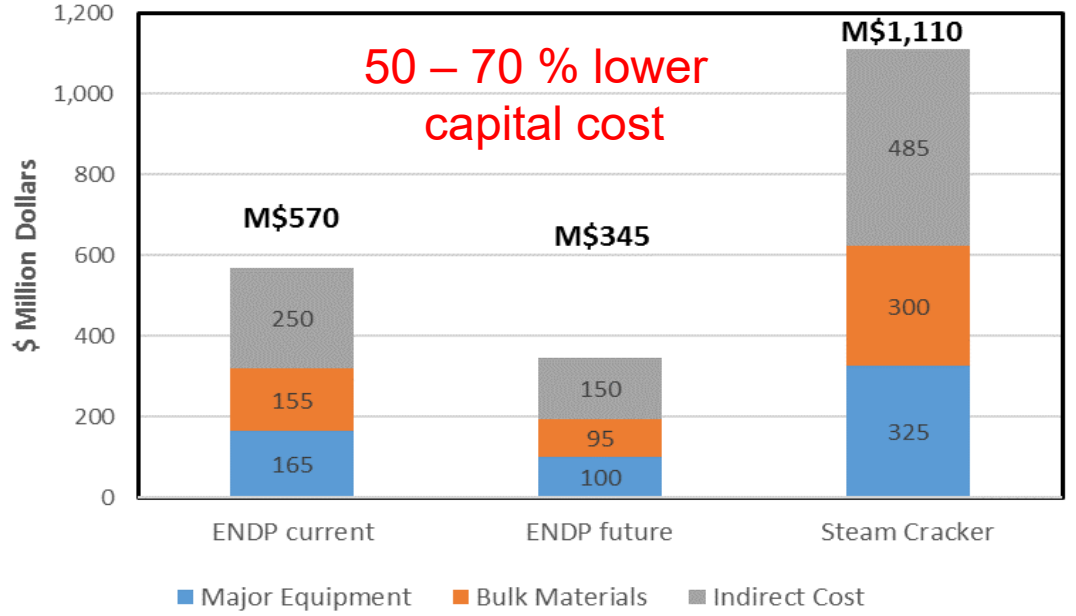
INL/EXT-19-56936

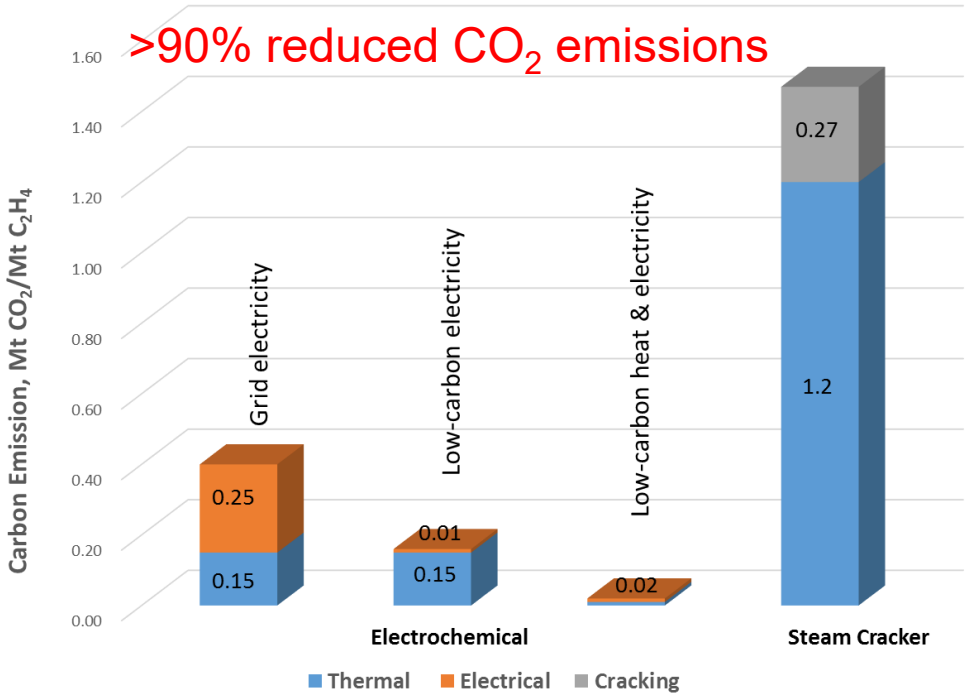


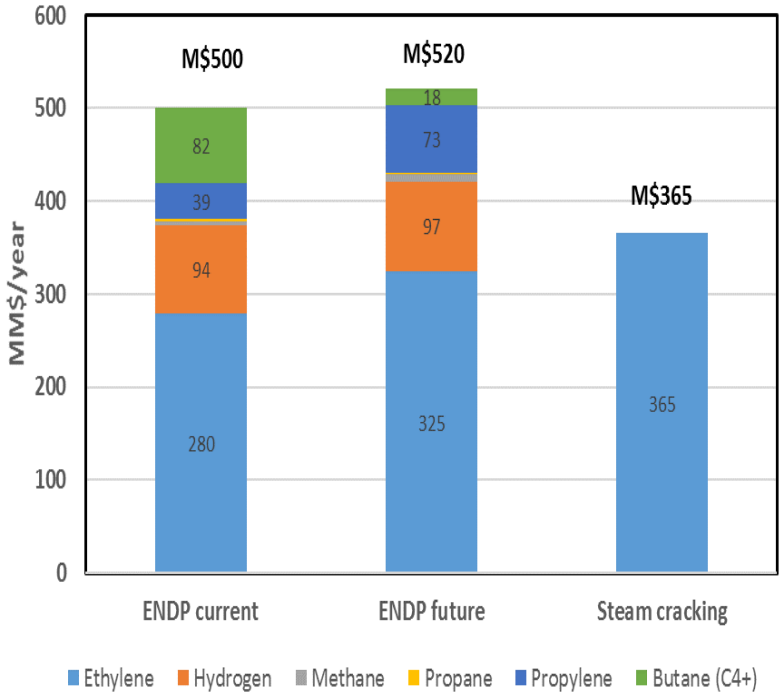






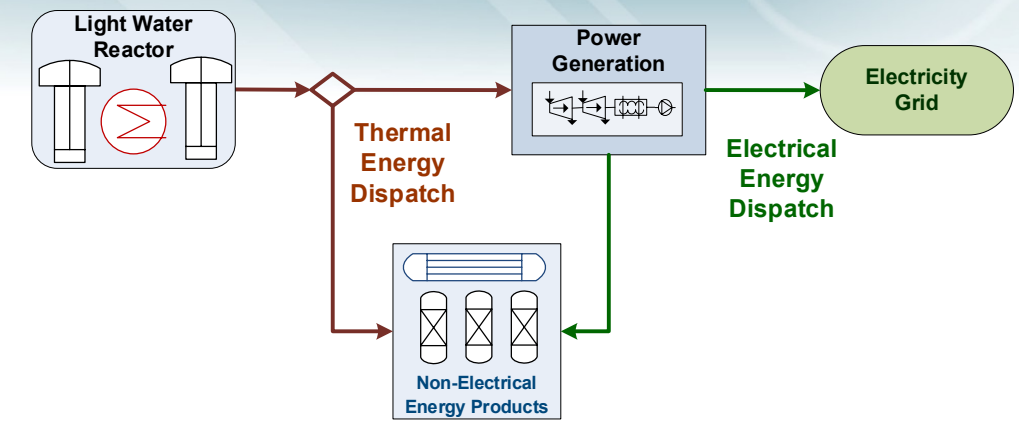


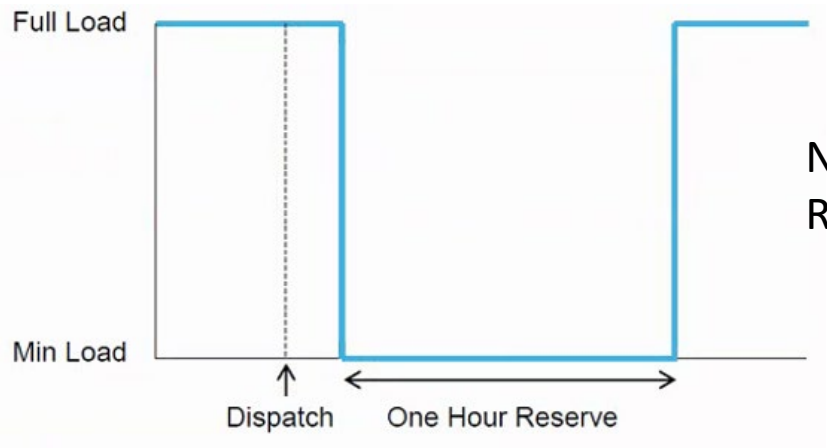




Higher Revenue

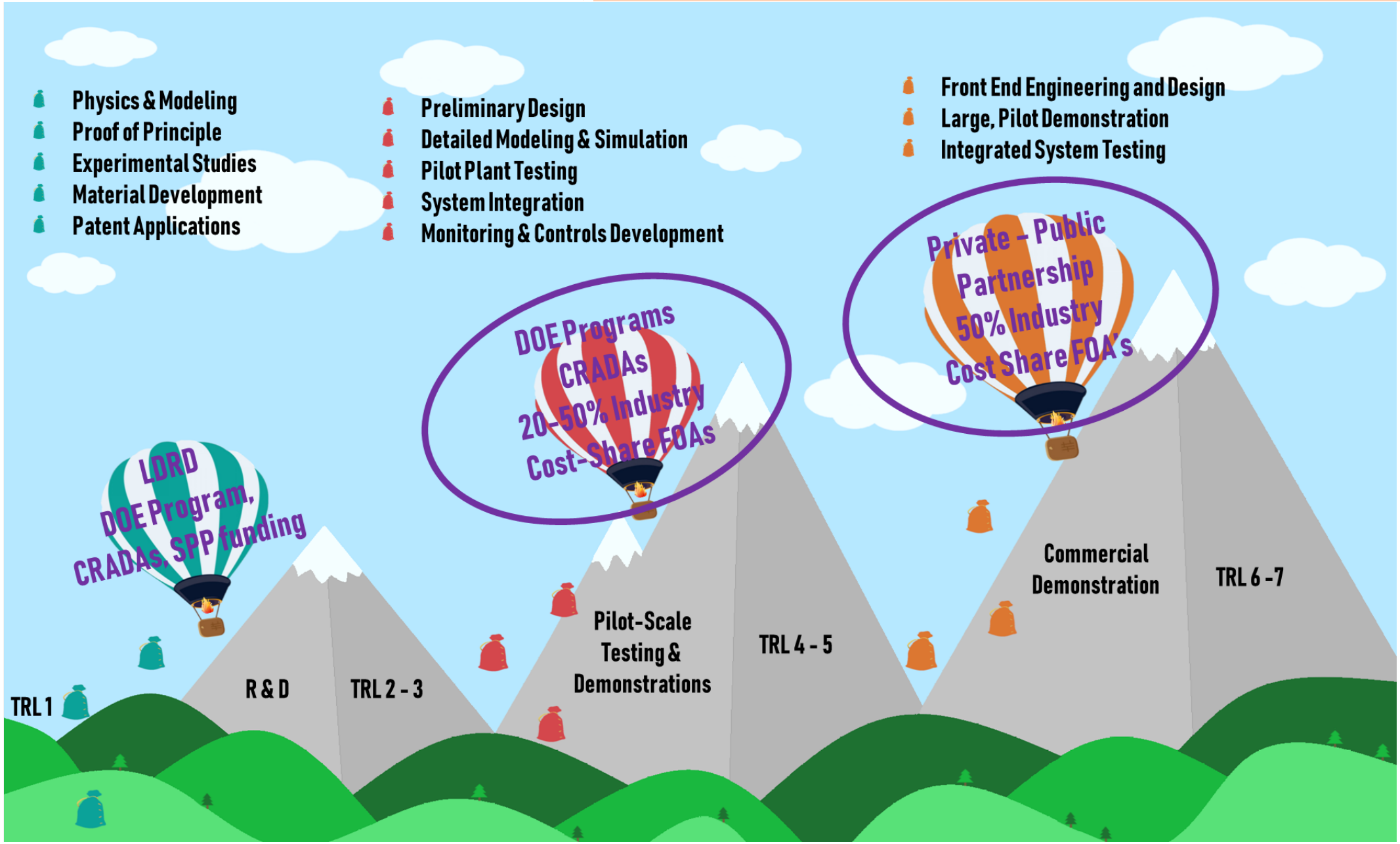
- Non-Spinning Reserve
  - Operating reserve (OR) is stand-by power or demand reduction that can be called on with short notice to deal with an unexpected mismatch between generation and load
  - Operating reserve requirements are defied by reliability standards established by the North American Eclectic Reliability Council (NERC) – typically a contingency to cover the loss of one and a half of the largest generator.
  - Non Spinning Reserve is a class of operating reserve that dispatchable generators and dispatachable loads can provide a 10-minute non-synchronized reserve





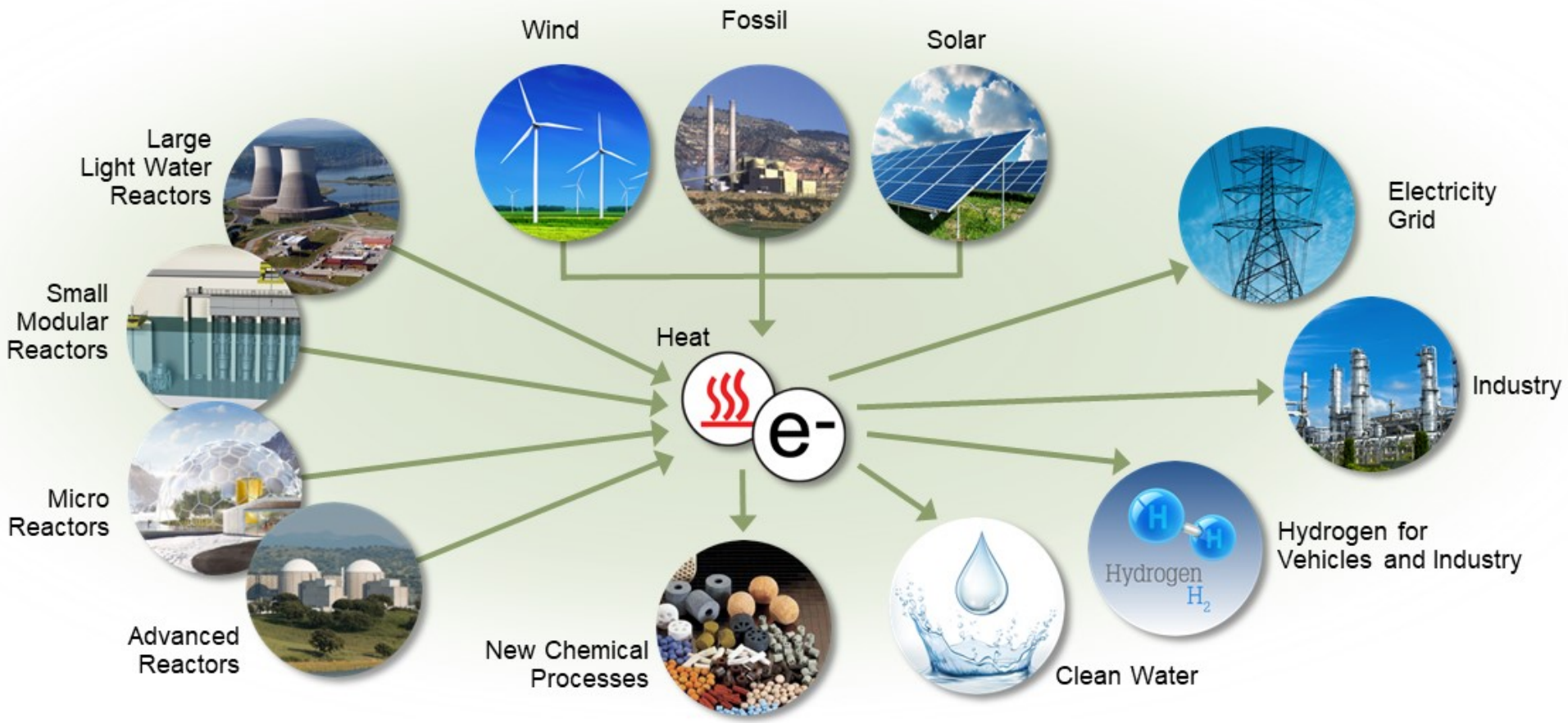
Non-Spinning Reserve Illustration

- How a Light Water Reactors Provides this Service
  - The industry user load (e.g. electrolyzer, desalination plant, etc.) is operating at full capacity and within 10 minutes notification it drops its load to its minimum operating point for some period (dispatchable load)
  - This service has the added benefit during off-peak hours of reducing the amount of gas-fired generation on standby that is required


Physics & Modeling
Proof of Principle
Experimental Studies
Material Development
Patent Applications
Preliminary Design
Detailed Modeling & Simulation
Pilot Plant Testing
System Integration
Monitoring & Controls Development
Front End Engineering and Design
Large, Pilot Demonstration
Integrated System Testing
LDRD
DOE Program,
CRADAs, SPP funding
DOE Programs
CRADAs
20-50% Industry
Cost-Share FOAs
Private – Public
Partnership
50% Industry
Cost Share FOA's
TRL 1
R & D
TRL 2 - 3
Pilot-Scale
Testing &
Demonstrations
TRL 4 - 5
Commercial
Demonstration
TRL 6 -7

Energy Systems for the Future

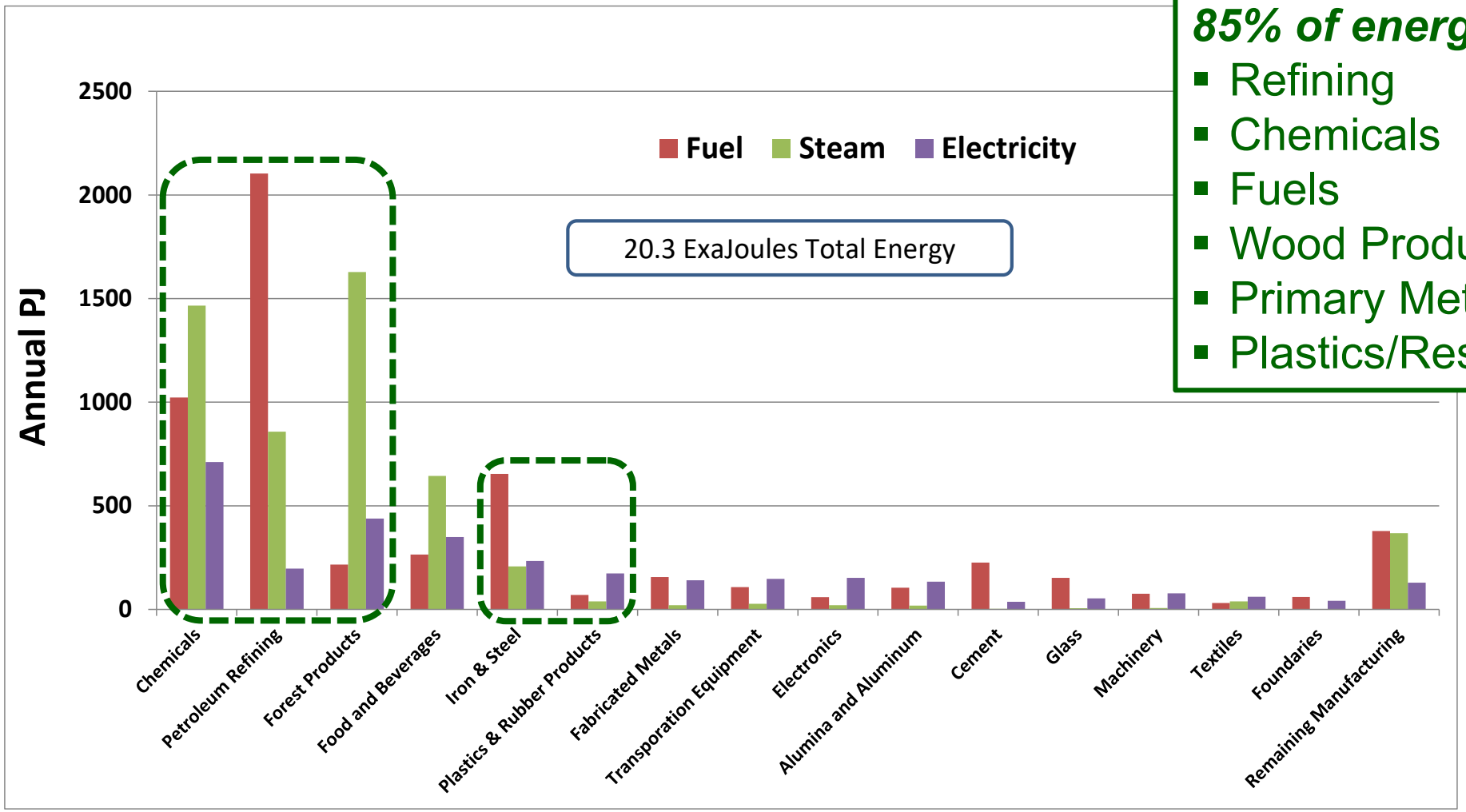
Goal: Energy utilization, generator profitability, and grid reliability and resilience through novel systems integration and process design



Flexible Generators ❖ Advanced Processes ❖ Revolutionary Design

INL Idaho National Laboratory

Large Industry Energy Use Breakdown (2010 Data)



85% of energy used by:

- Refining
- Chemicals
- Fuels
- Wood Products/Paper
- Primary Metals
- Plastics/Resins

Generation and Use of Thermal Energy in the United States Industrial Sector and Opportunities to Reduce its Carbon Emissions, December 2016, INL/EXT-16-39680 and NREL/TP-6A50-66763, http://www.osti.gov/scitech/biblio/1334495-generation-use-thermal-energy-industrial-sector-opportunities-reduce-its-carbon-emissions

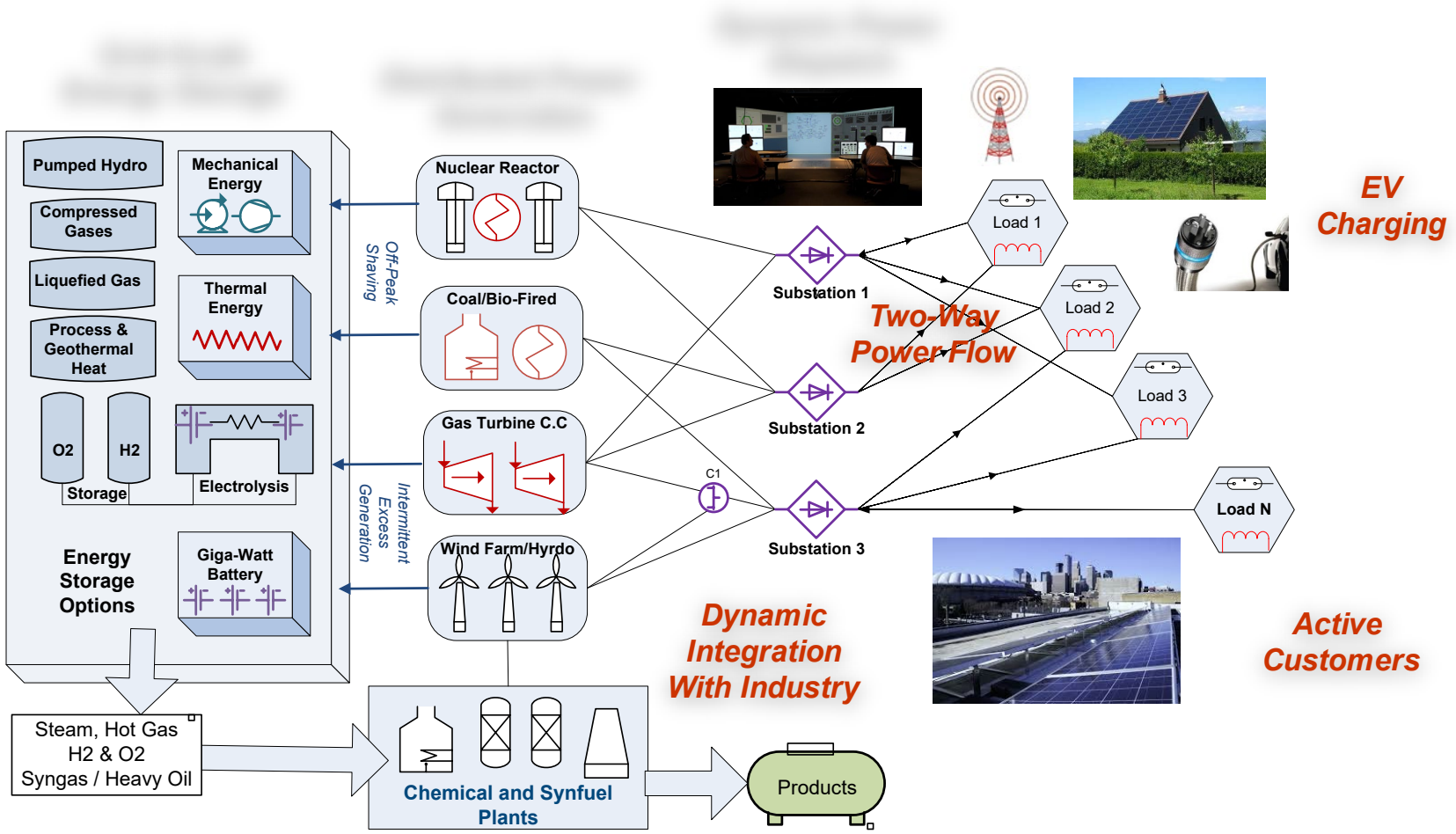
Coordinated Energy Systems

- Holistic Integration of the energy system
- Involve electrical, thermal, and chemical networks
- Utilize energy storage on various scales
- Provide reliable, sustainable, low-emissions, most affordable energy

Tightly Coupled Hybrid Systems

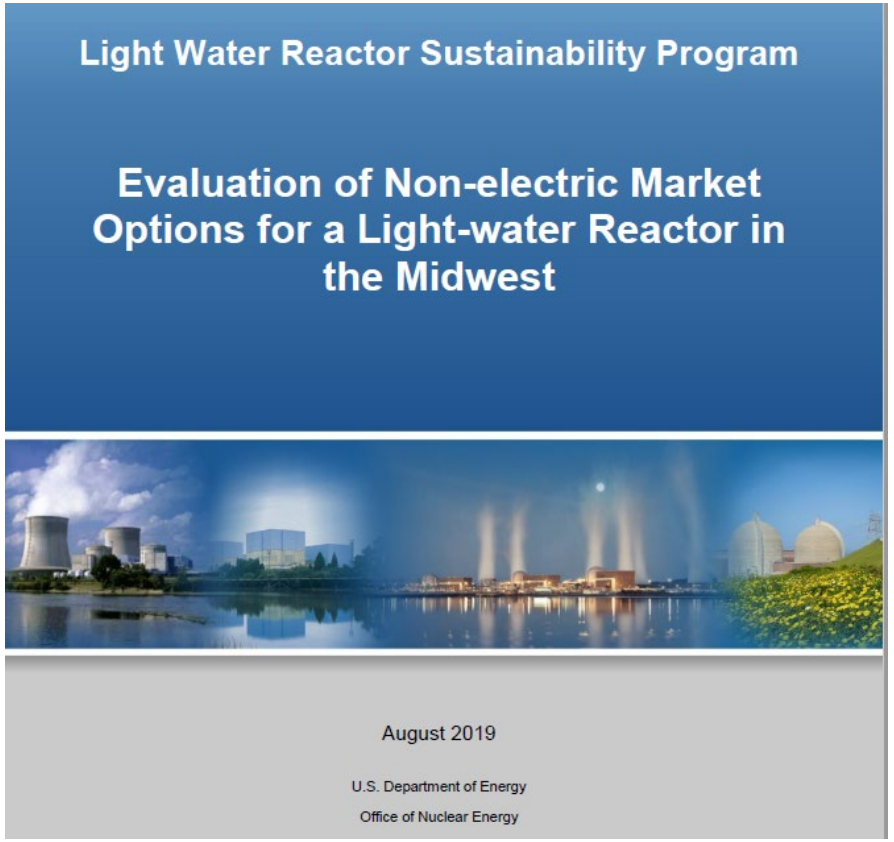
- Involve thermal, electrical, and process intermediates integration
- More complex than co-generation, poly-generation, or combined heat and power
- May exploit the economics of coordinated energy systems
- May provide grid services through demand response (import or export)

Evolution of the Electrical Grid



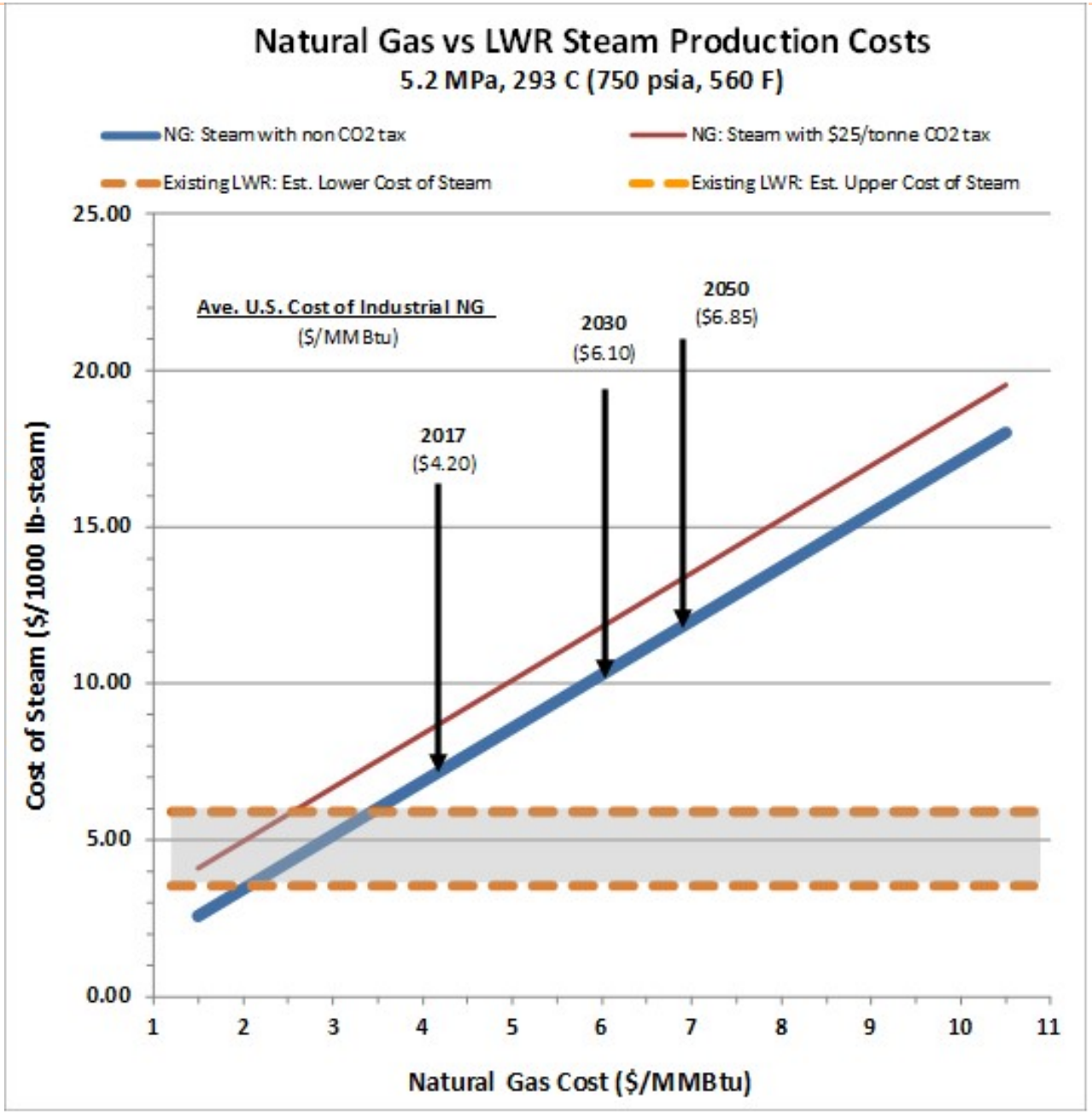
What assumptions have to be true for this proposition to be viable?

1. Must have a low cost of energy
   - » Assured supply
   - » Low price volatility
2. Cost of electrolysis technology is reduced by:
   - » High technology readiness
   - » High volume, low-cost manufacturing supply chain
   - » Reducing commercial risk through demonstration projects
3. Large commercial markets that are relative inelastic
   - » Transportation sector continues strong
   - » Fossil fuels costs are presently near a minimum threshold
4. Policy and regulations provide an initial boost
   - » Regulations that incentivize air pollutant emissions control
   - » Grid market rules adapt to optimize integrated energy systems
   - » Private-public partnerships help kickstart projects (e.g., cost-shared demonstrations, loan guarantees, tax incentives)



INL/EXT-19-55090

- Existing nuclear reactors compete with natural gas when producing steam (and heat)
- Nuclear power plant costs are coming down as owners look to reduce costs through plant modernization and other measures
- Nuclear fuel costs will remain flat for decades to come
- Spent nuclear fuel is relatively small and can be held in dry storage until a permanent repository is available



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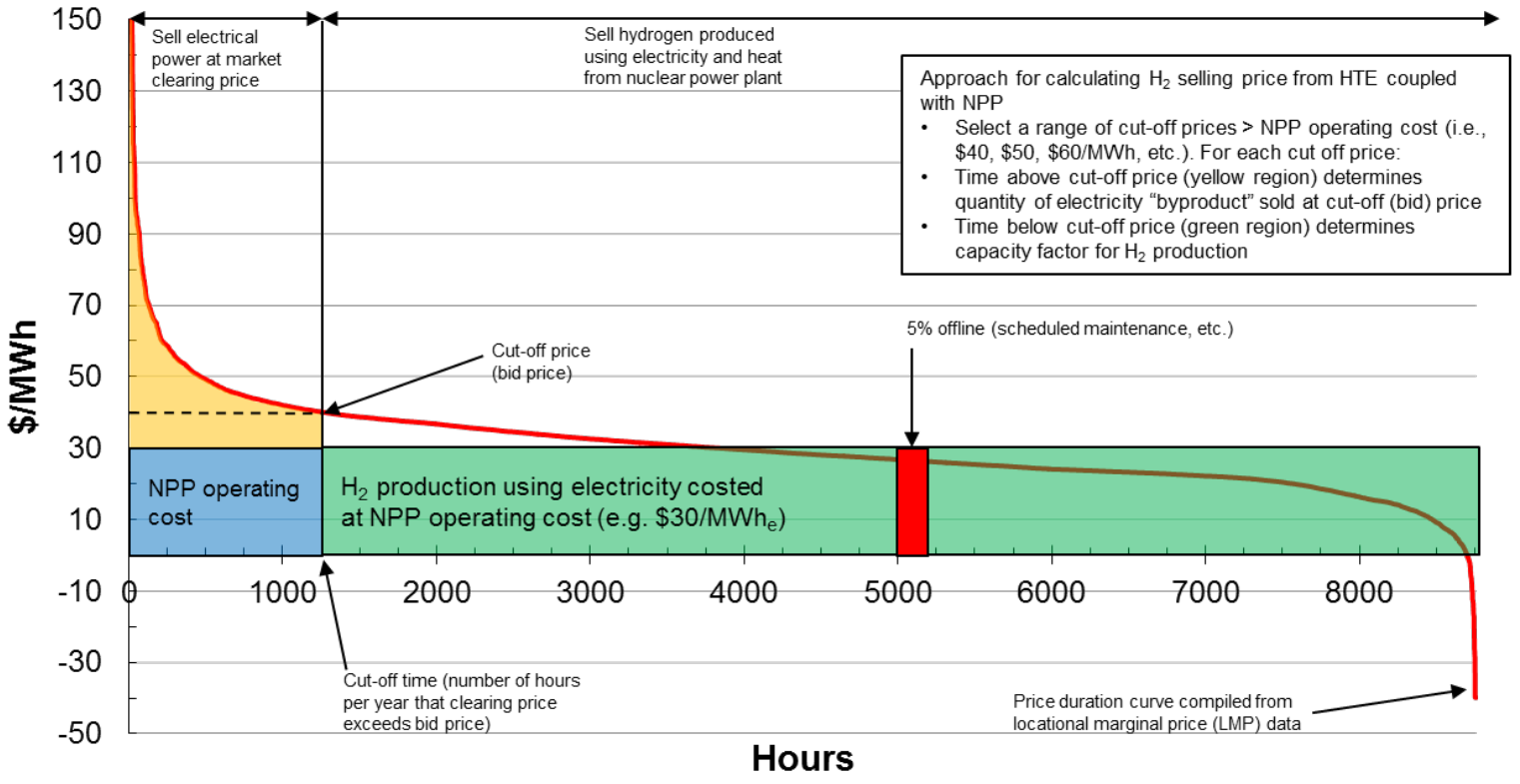
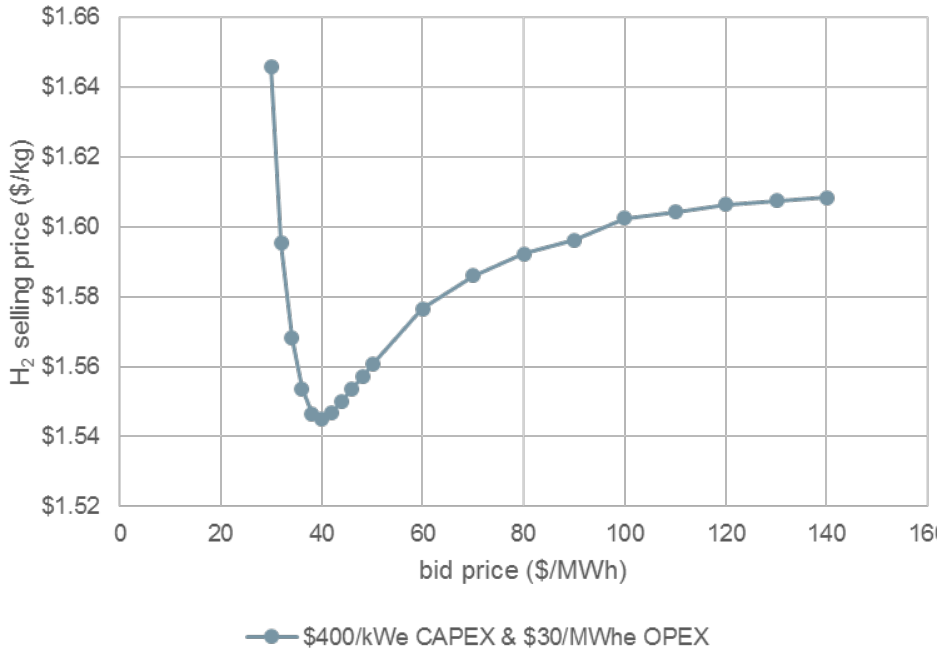
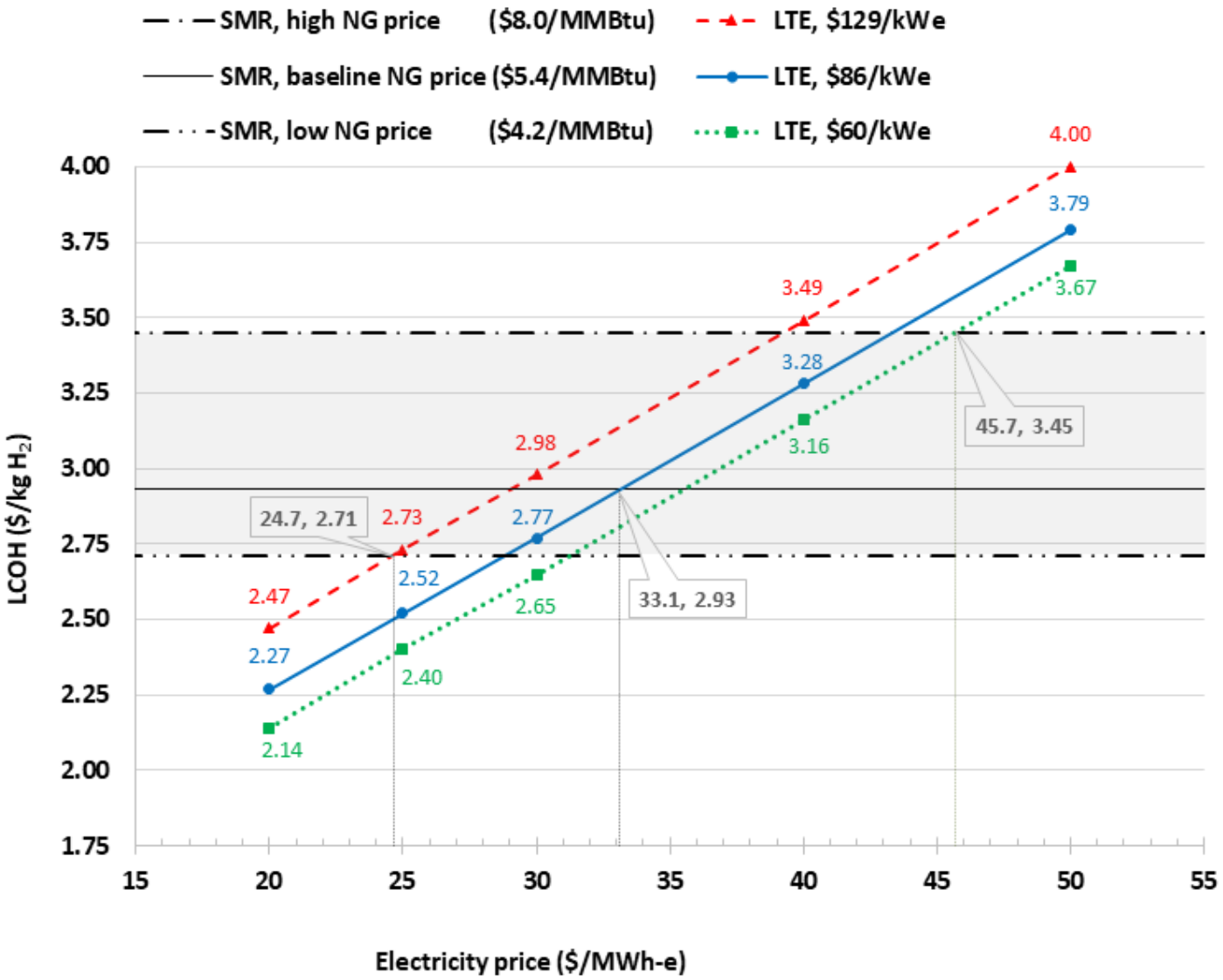


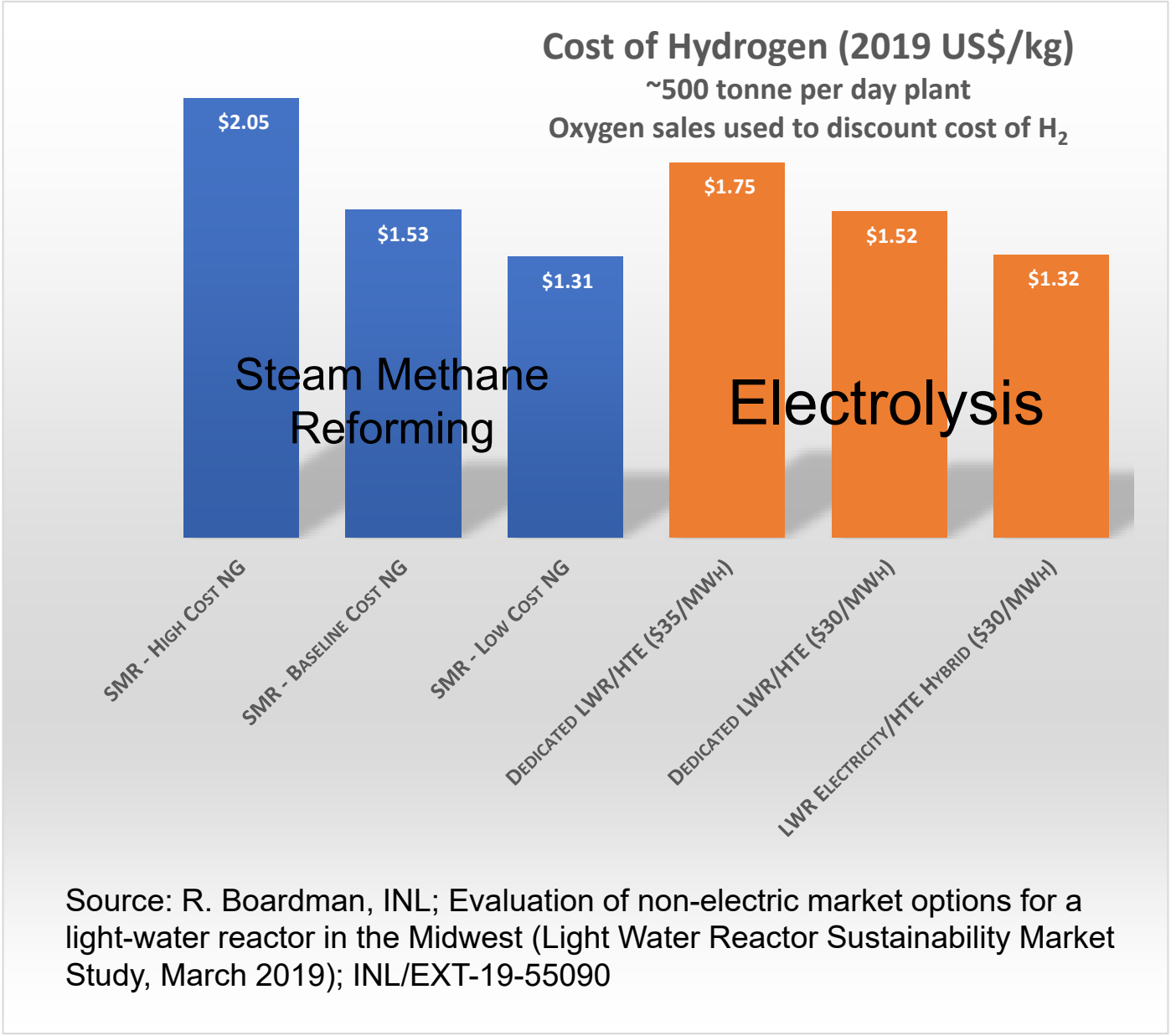


Minimum hydrogen production costs versus cut-off selling price for producing/selling electricity

Small-scale (24 tpd H_2) local hydrogen production



"nth-of-a-kind" LTE PEM outperforms SMR with LWR cost of electricity <$35/MWe-hr

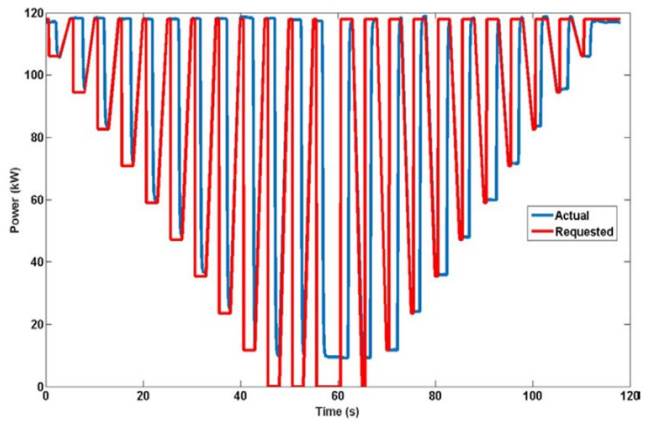


Source: R. Boardman, INL; Evaluation of non-electric market options for a light-water reactor in the Midwest (Light Water Reactor Sustainability Market Study, March 2019); INL/EXT-19-55090

Grid Integration

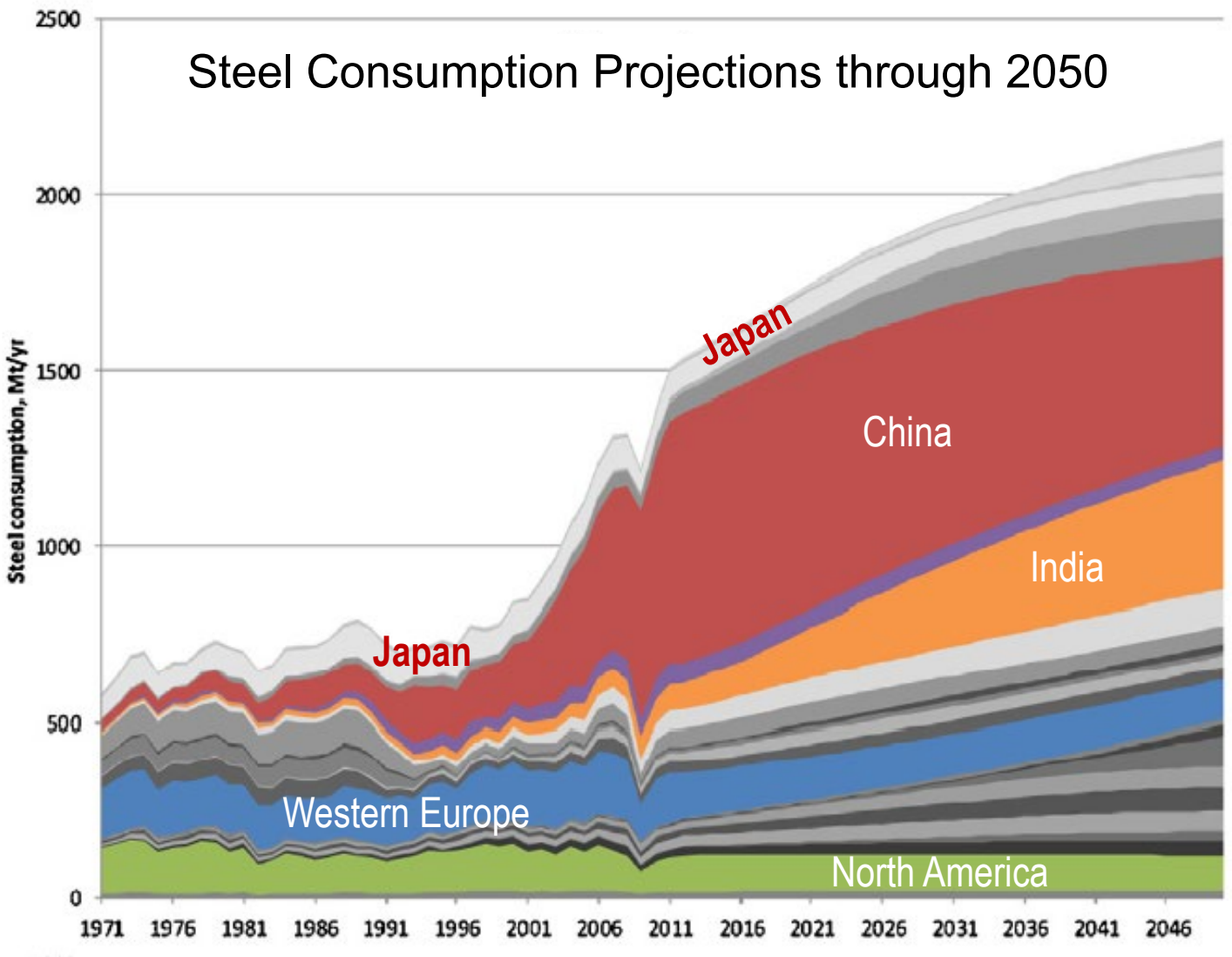
- Electrical Coupling
- Controls Coupling
- Thermal Coupling
- Tightly coupled grids

Low Temperature Electrolysis Grid Stabilization Demonstration



Dynamic High Temperature Electrolysis Grid & Thermal Integration Activities

World Apparent Steel Market



World Steel Association's Short Range Outlook, 2017
Finished Steel Production Breakdown

Region	Amount (million tonnes)	% change since 2015
China	667	-0.80
Japan	104	-1.0
Other Asia & Oceana	244	16
E.U. (28)	160	4.2
Other Europe	43.2	6.7
CIS	51.9	2.5
North America	138.5	3.1
Central & South America	42.7	-5.4
Africa	40	3.5
Middle East	57	5.5
World	1549	3.2

These sources indicate steel use will increase ~1% annually

Source: Bas. J. van Ruijven, et al., Long-term model-based projections of energy use and CO_2 emissions from the global steel and cement industries, Resources, Conservation, and Recycling, 112 (2016) 15-36