“New World Energy”

Dr. Joseph D. Smith

Laufer Endowed Energy Chair Professor

Director of Energy Research and Development Center

Briefing Outline

- How to power the New-World?
- Sustainability, Resilience and Useful Energy
- Next Generation Biofuels
- Technology Readiness Level
- Deploying Next Gen Energy Systems
- Hybrid Energy = Resilient Energy
- Conclusions

Energy Today

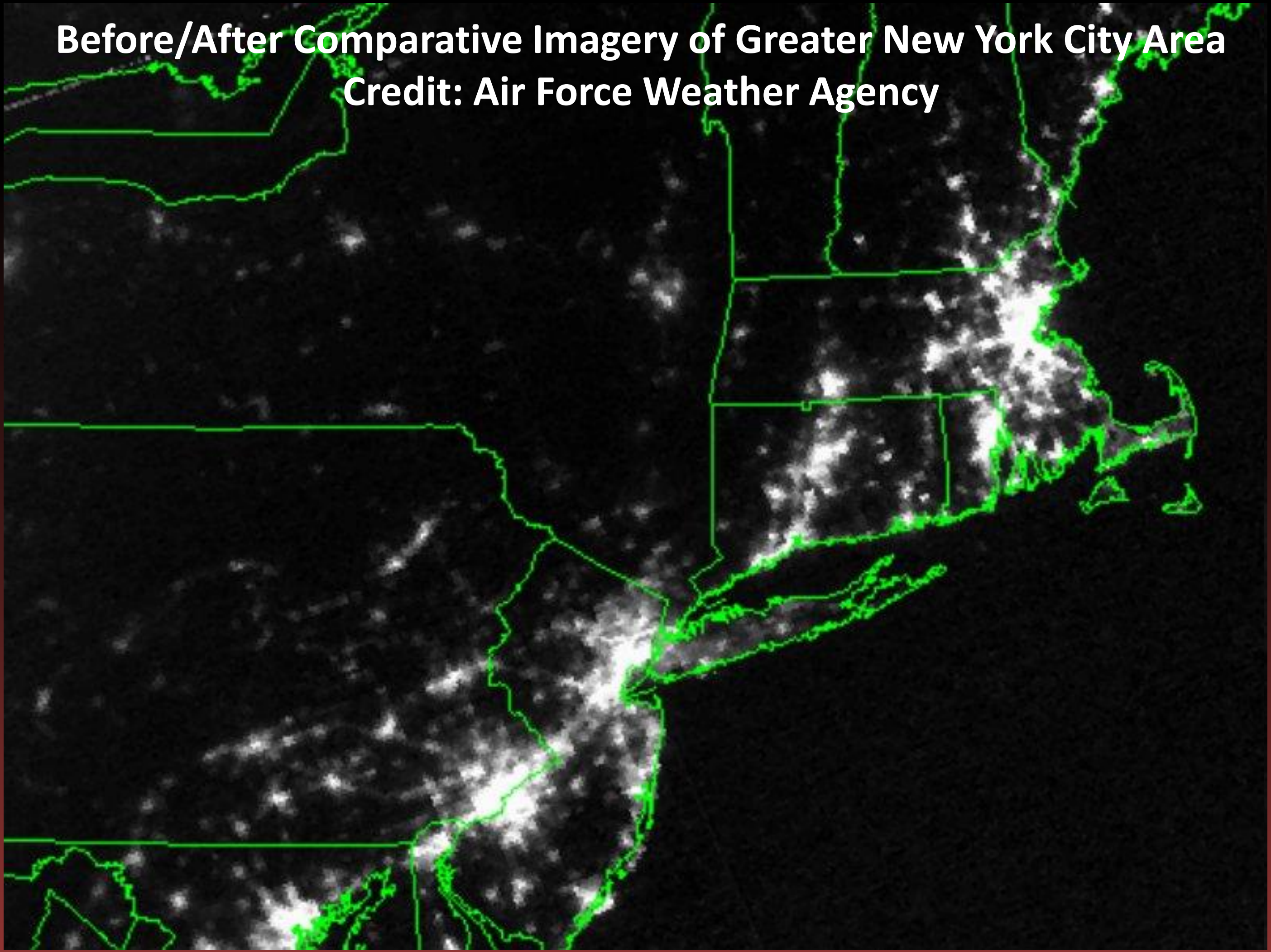
Resilient Energy: Our Grand Challenge

- Global population marches on
  - Over 8 billion by 2030; 9 billion by 2050
  - Globalization of economies continues
  - 3 to 5 fold increase in economic activity
- Access to stable, affordable energy is key to peace and prosperity
  - 40% increase in demand by 2030 (IEA estimate)
  - 2-3 fold increase in demand by 2050 (WBCSD estimate)
- Greatest energy consumption growth in non-OECD countries
  - China, India and Middle East account for over 90% of the increase

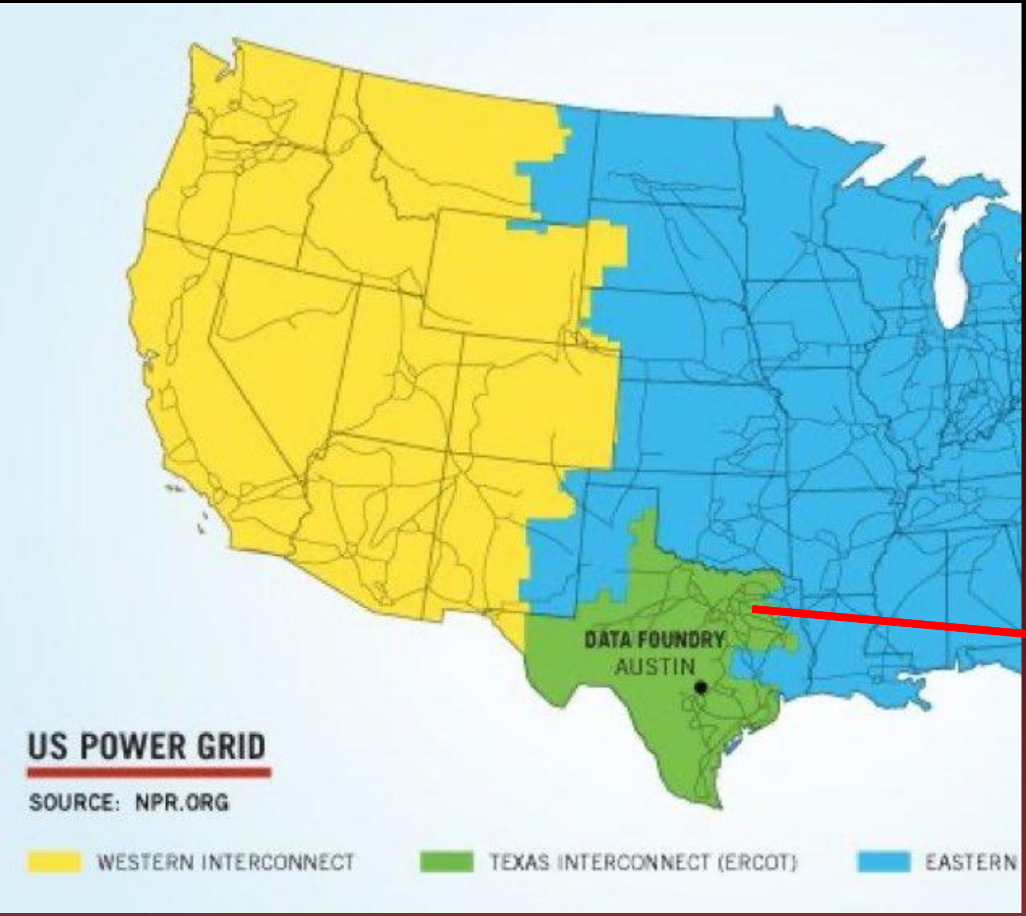
Sources: United Nations Population Division And United States Energy Information Agency

Resilient Supply depends on Stable Grid

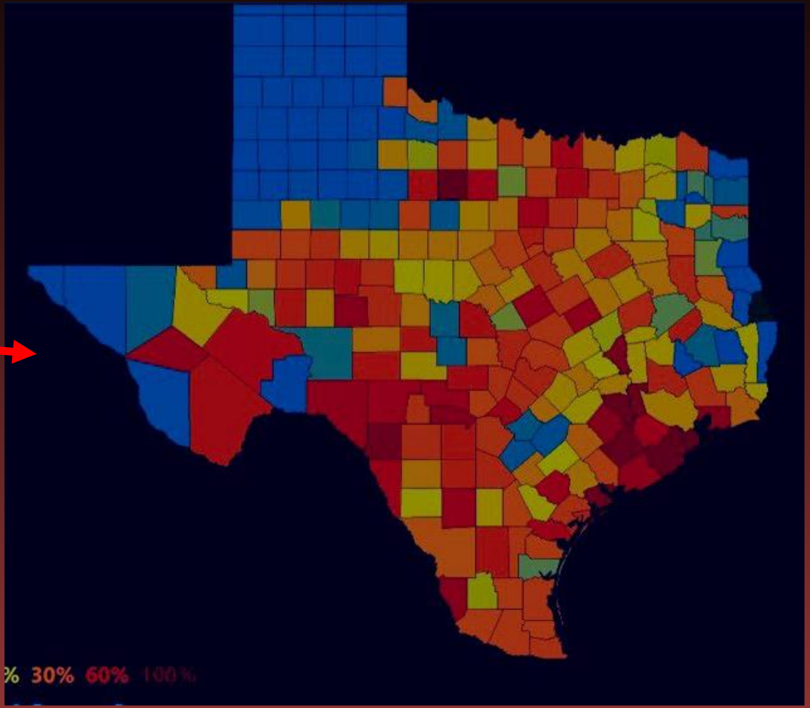
Great Northeast Power Blackout of 2003



2021 Texas Grid Failure:
3 US Grids



Texas Grid Outages on 16Feb21



2021 Texas Grid Failure:

Unexpected Demand

A comparison of the current situation vs ERCOT's expectations for winter are shown below.

Capacity, GW	Expected Forecast	Extreme/Contingency Forecast	Actual Conditions (8am CST 2/15/21)
Peak Load	57.7	67.2	74.5
Resource Outages	8.6	14.0	26.6
Wind Output	7.1	1.8	4.5
Solar Output	0.3	[0]	0
Total Generating Capacity	73.1	68.6	53.4
Remaining Reserve Capacity	16.2	1.4	-21.1
Operational Conclusion	Normal operations	Emergency measures	Widespread outages

Source for values under Expected and Extreme Forecasts: ERCOT SARA Winter 2020/21. Notes: No contingency forecast given for solar. ERCOT's worst combined contingency forecast uses high demand and high outage, but no adjustment for wind (wind contingency is shown as a separate case). Total generating capacity at 8am roughly estimated as actual load plus 2 GW of operating reserves. Peak load under "actual" is the day-ahead load forecast.

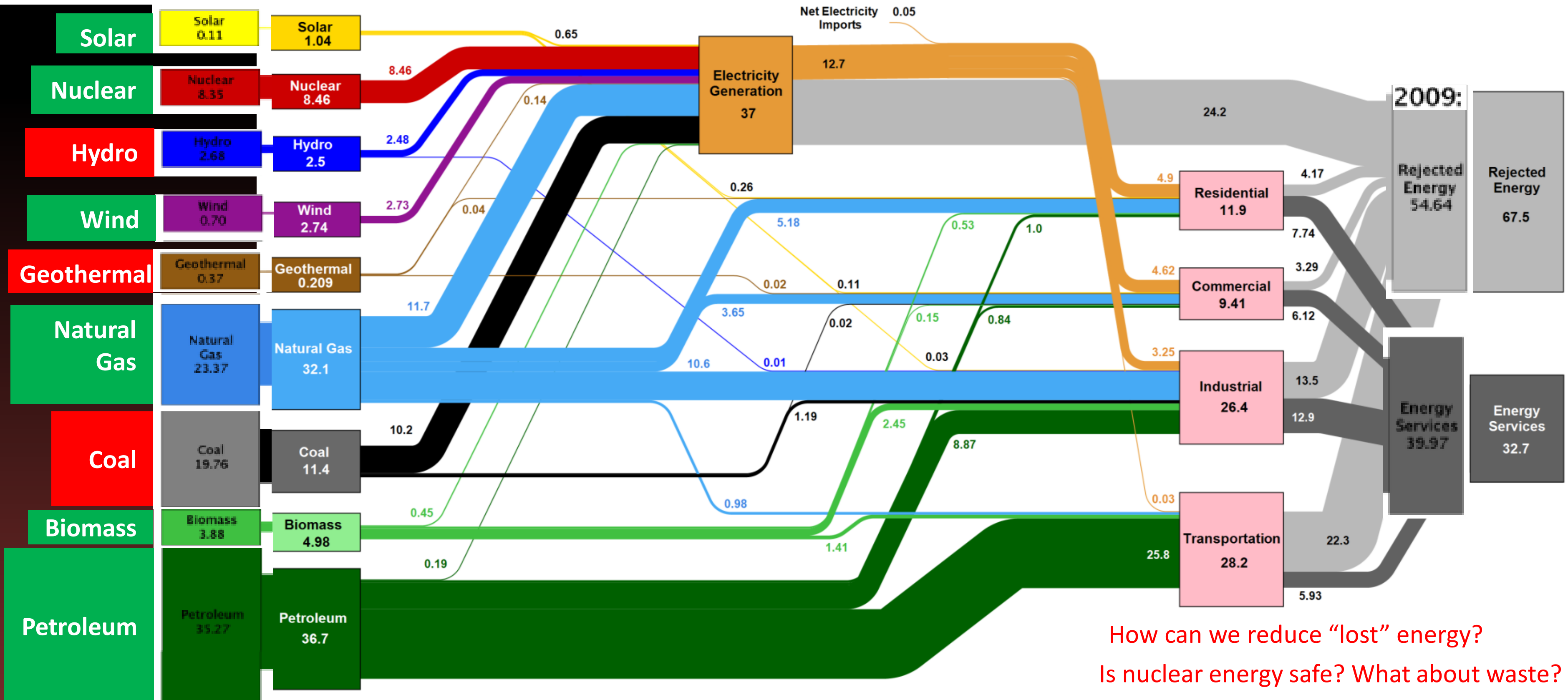
Texas Grid Failure:
Causes

- **Thermal outages, rather than renewables, are the main supply gap:** Around 20 GW of generation is on outage as of mid-day. Total wind output is slightly below expectations, but the main supply issue is lack of available thermal generation (both gas and coal) due to freezing conditions.
- **The weather has caused major issues in gas markets, affecting power:** Gas production in Texas dropped at least 16% due to well freeze-offs and shutdown of processing plants due to cold weather. Spot gas prices soared to $100-200/MMBtu, and generators without firm contracts may have difficulty sourcing adequate supply.

Past Energy Consumption

2019 (100.2Q): 80.1% Fossil (Coal, Petro, Gas), 8.5% Nuclear; 11.4% Renewable (Biomass Solar, Wind, Hydro, Geo)

2009 (94.6Q): 82.9% Fossil (Coal, Petro, Gas), 8.8% Nuclear; 8.2% Renewable (Biomass Solar, Wind, Hydro, Geo)



How can we reduce “lost” energy?

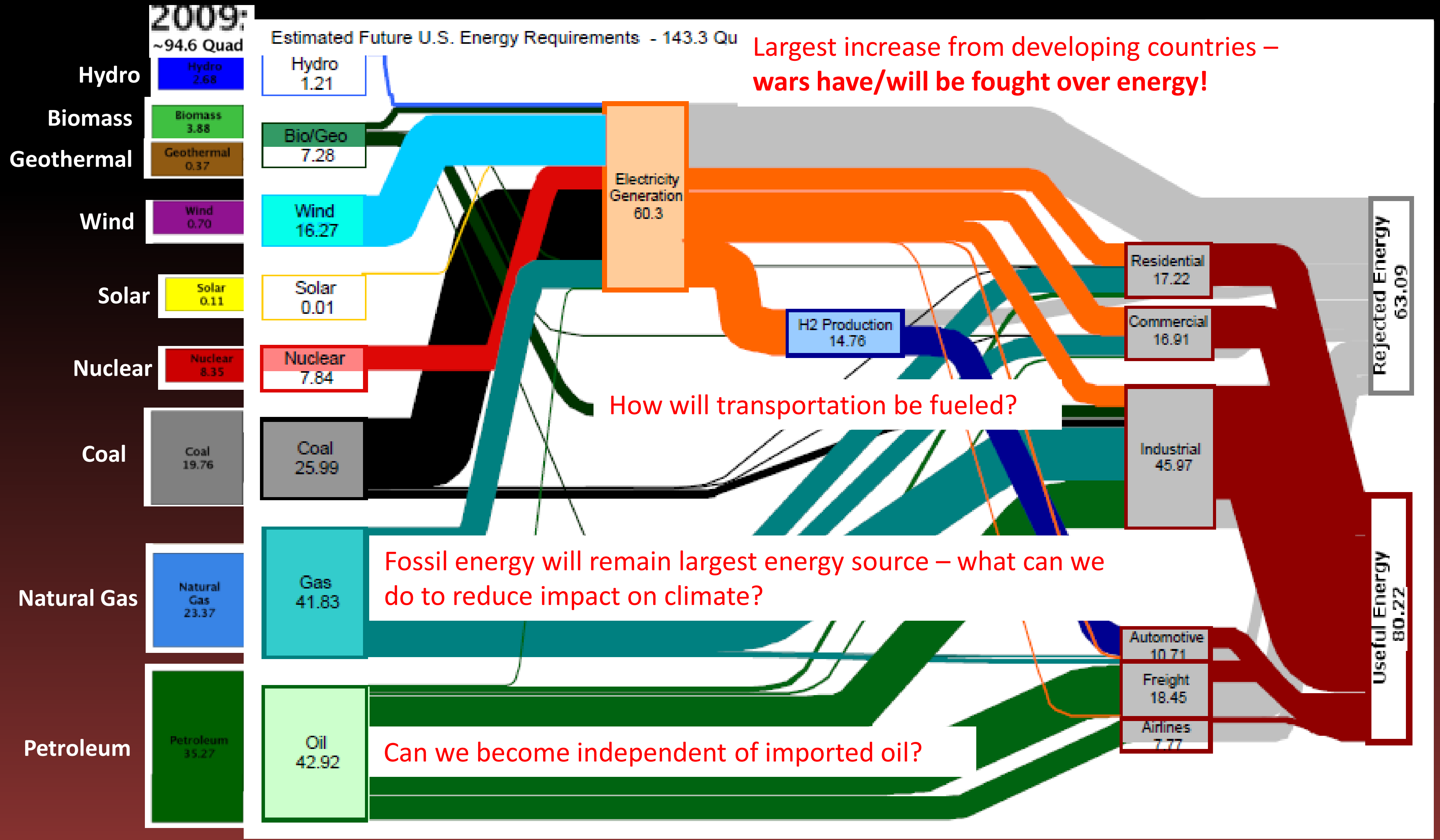
Is nuclear energy safe? What about waste?

What impact does fossil energy have on the climate?

Can renewable energy replace fossil energy? At what cost?

Where do our liquid fuels come from?
At what cost to our economy?

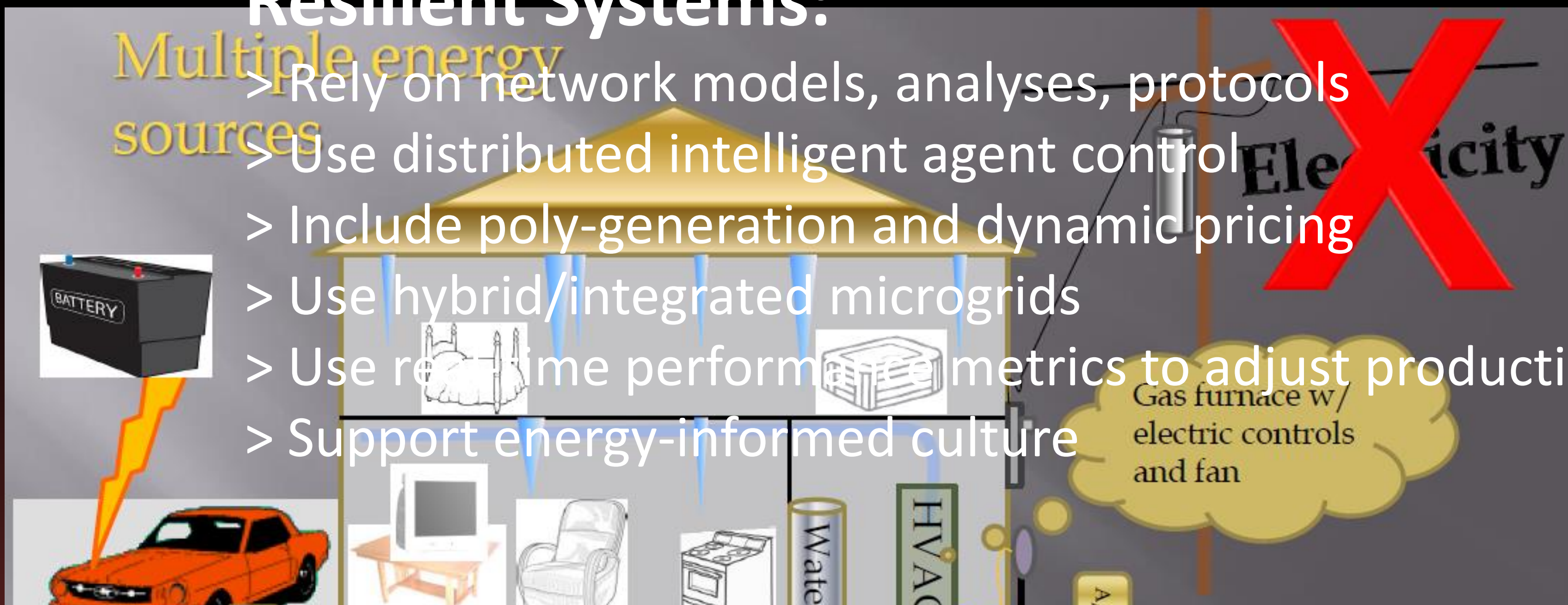
Future Energy Consumption (2050 EIA estimate)



Leighty, B., "Energy Storage with Anhydrous Ammonia: Comparison with other Energy Storage," *Ammonia: The Key to US Energy Independence*, 29 – 30 September, Minneapolis, MN (2008)

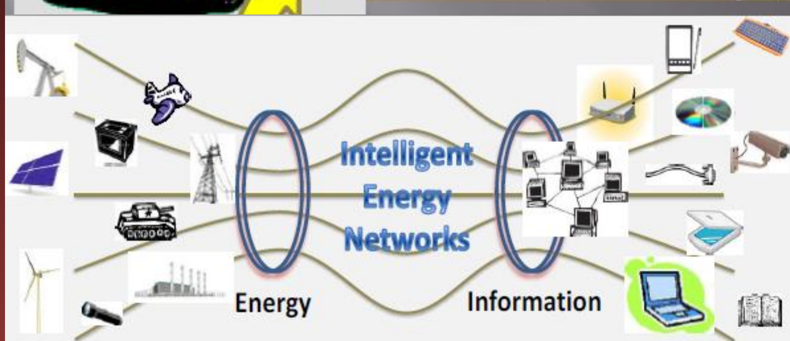
Next Generation Energy Technology

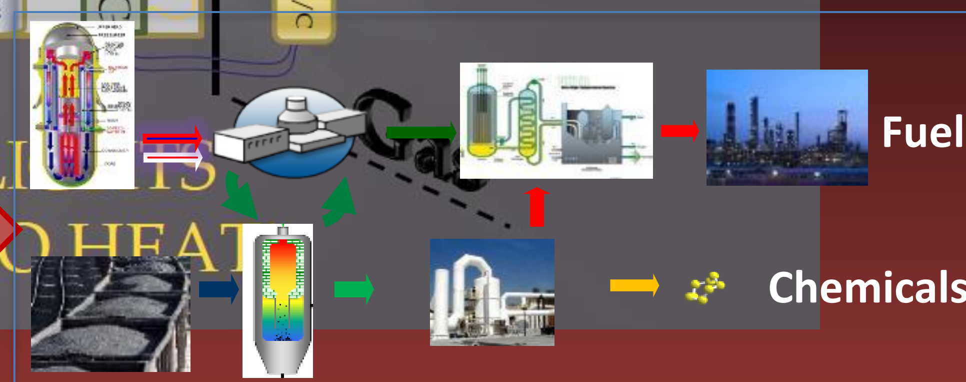
What's wrong with this picture?



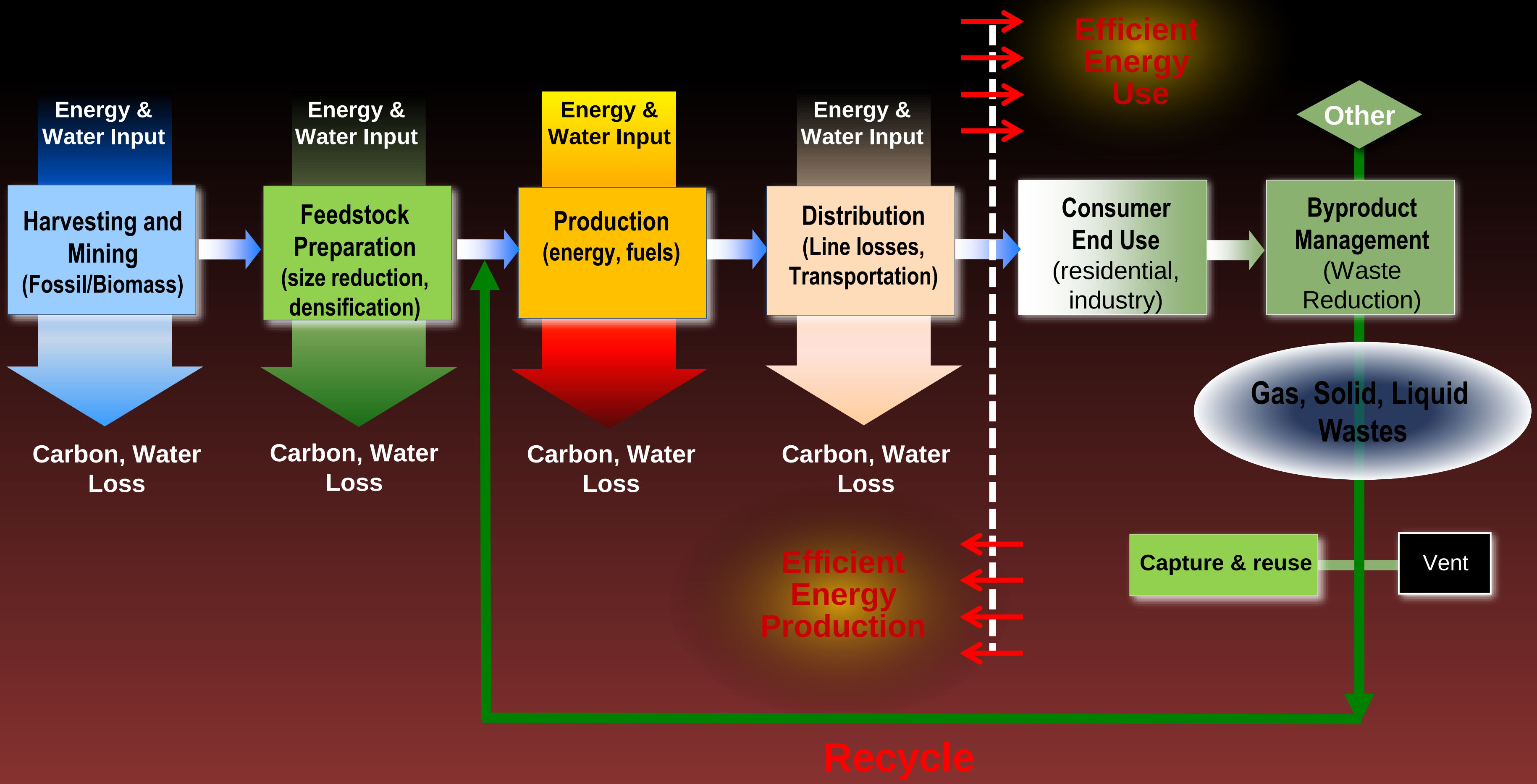
Resilient Systems:

> Rely on network models, analyses, protocols
> Use distributed intelligent agent control
> Include poly-generation and dynamic pricing
> Use hybrid/integrated microgrids
> Use real-time performance metrics to adjust production
> Support energy-informed culture

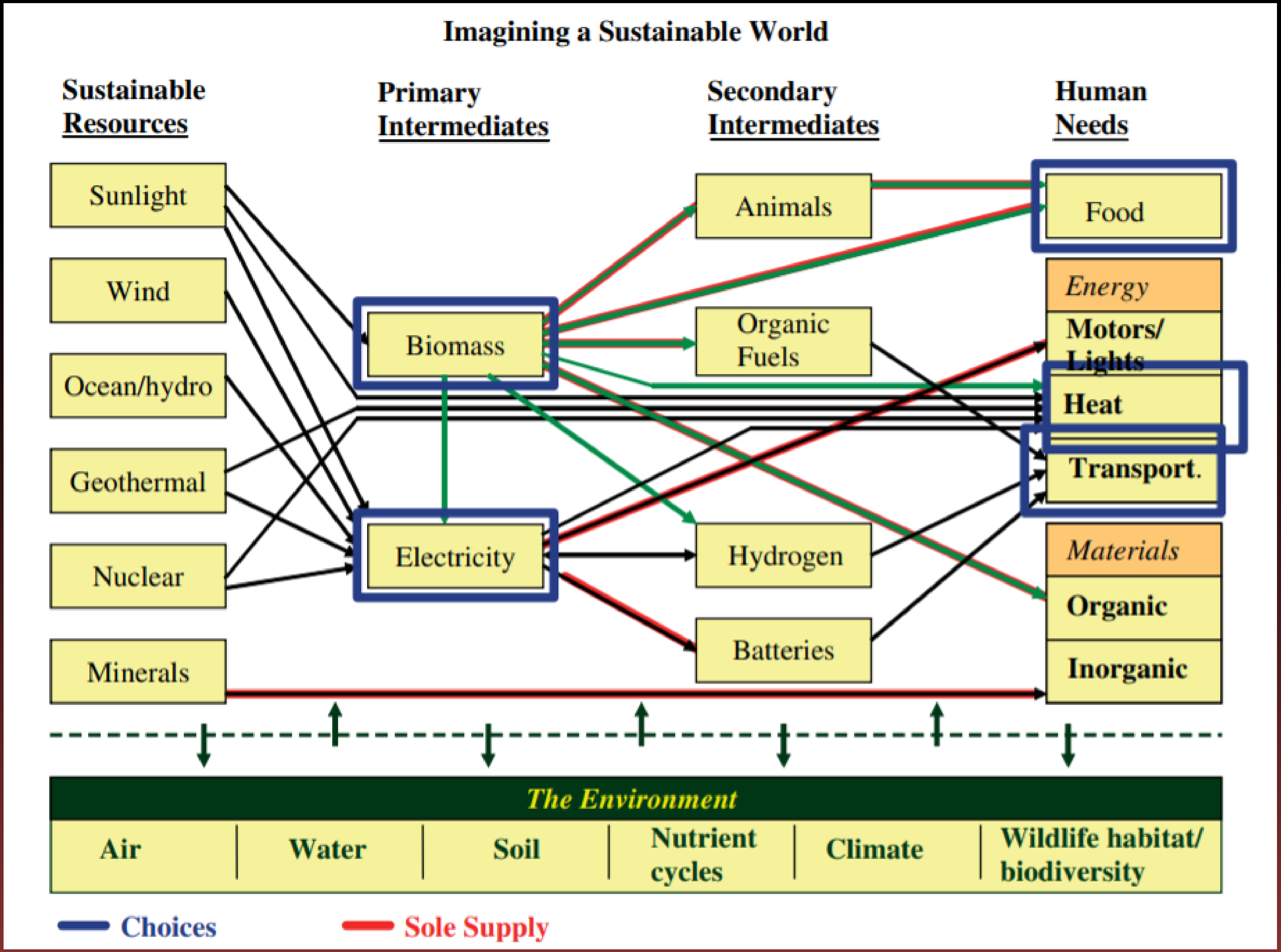




Resilient Systems require "Full" Lifecycle Analysis to optimize sustainability

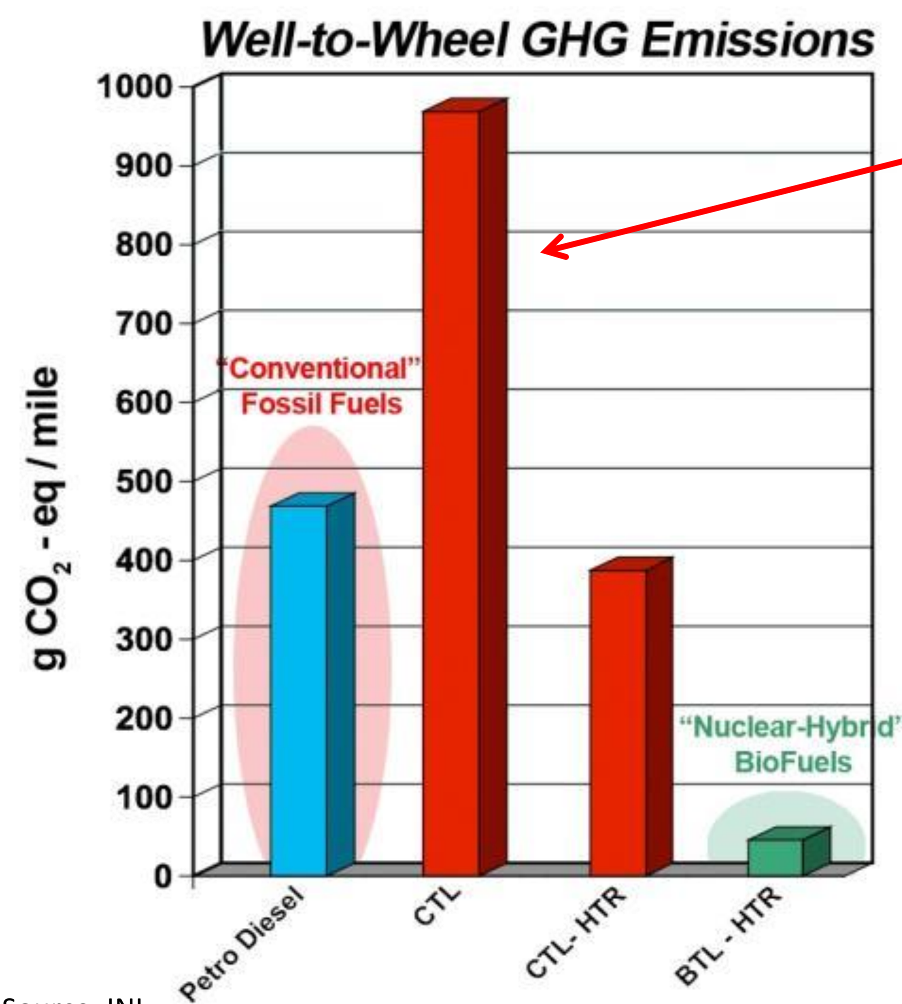


Resilient Energy starts with Choices



Source: Lee R. Lynd, L.R., Larson, E., Greene, N., Laser, M., Sheehan, J., Dale, B.E., McLaughlin, S., Wang, M., (2009) “The role of biomass in America’s energy future: framing the analysis,” *Biofuels, Bioprod. Bioref*. 3:113–123

Resilient Energy Systems more efficient and cleaner



Source: INL

Fischer-Tropsch:

$$CO + 2H_2 \longrightarrow -(CH_2)- + H_2O$$

SMR:

$$2H_2O + CH_4 \longrightarrow 4H_2 + CO_2$$

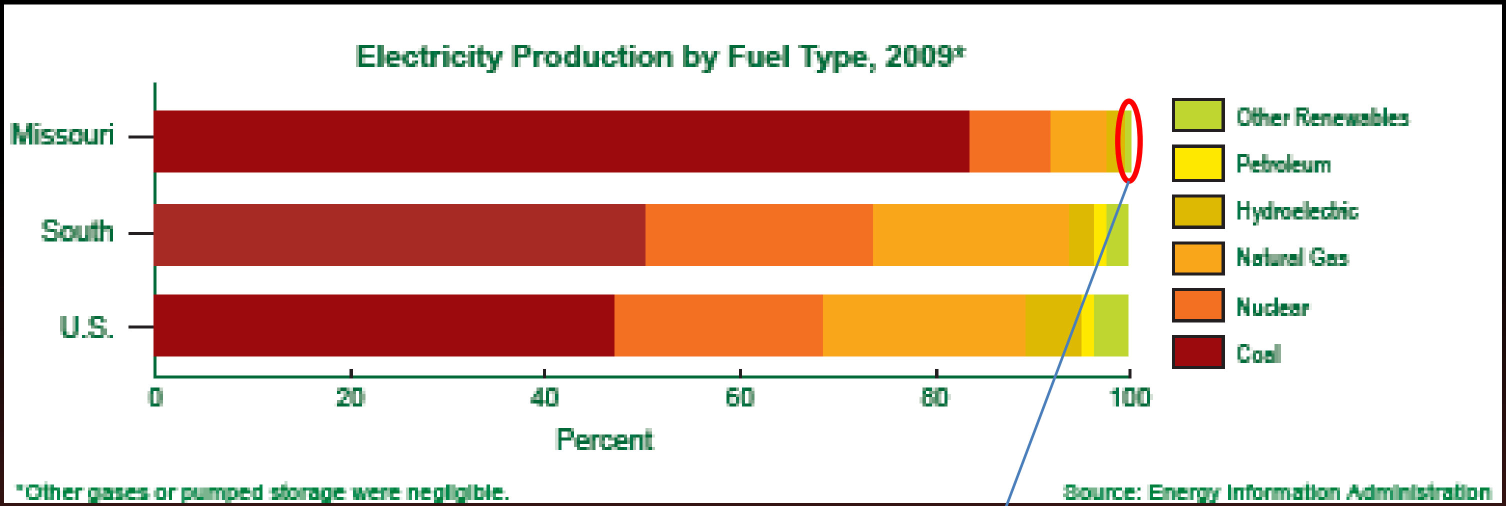
SMR (Steam/methane reforming)

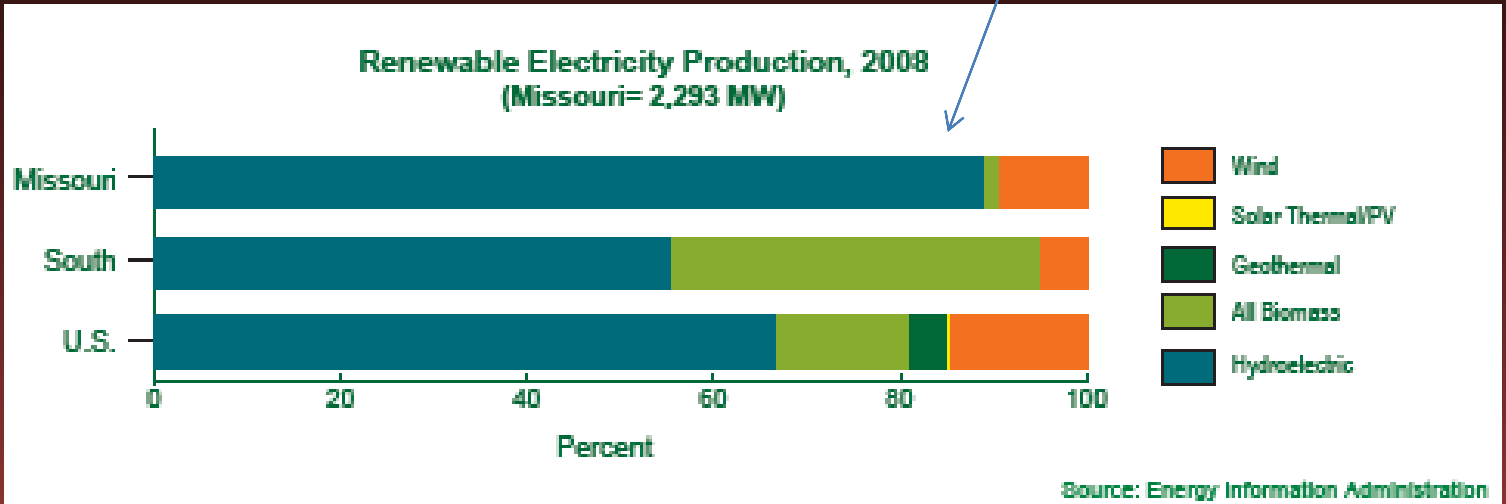
> Used to produce hydrogen for upgrading unsaturated hydrocarbons
> Requires high temperature steam produced via process heaters - generates extra CO2 emissions

Fischer-Tropsch = catalytic process

> converts "syngas" to higher molecular weight liquid hydrocarbon fuels

Bioenergy Comparison





Source: Smith, J.D., et.al., "Assessment of Missouri's Biomass/bioenergy Industry," June (2012).

Bioenergy Production

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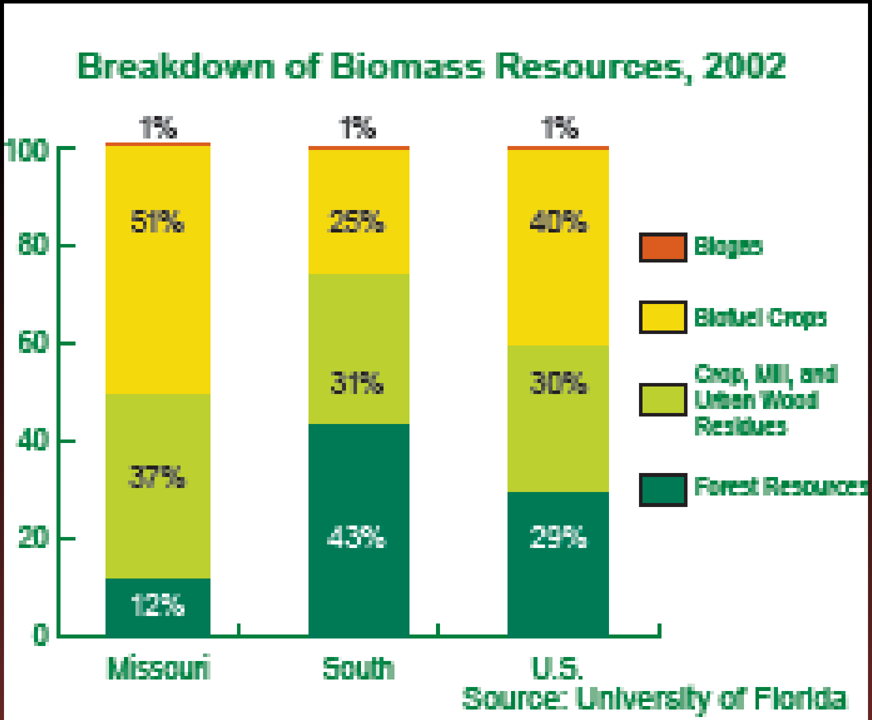
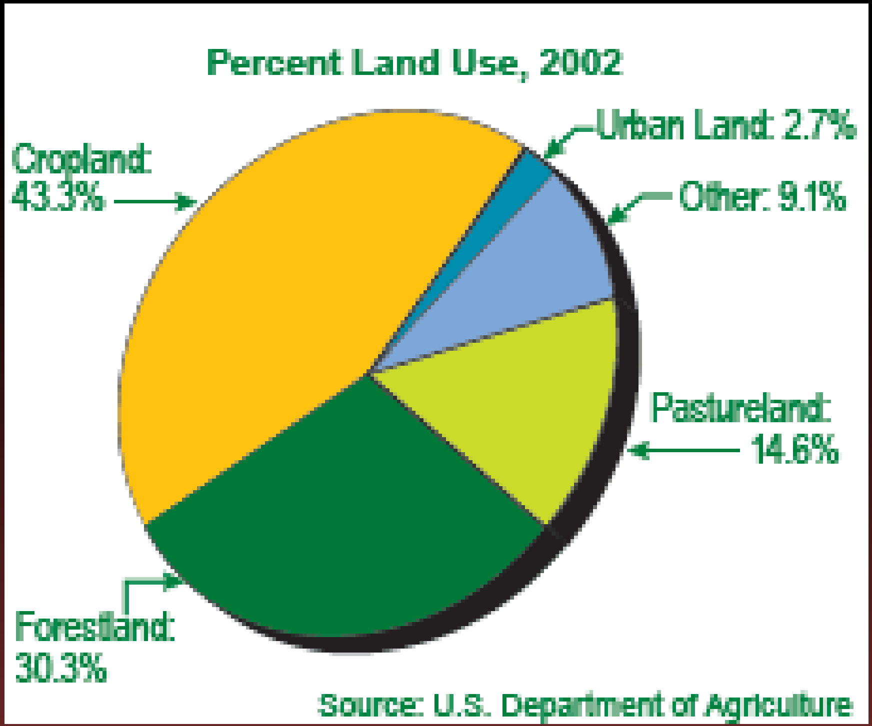
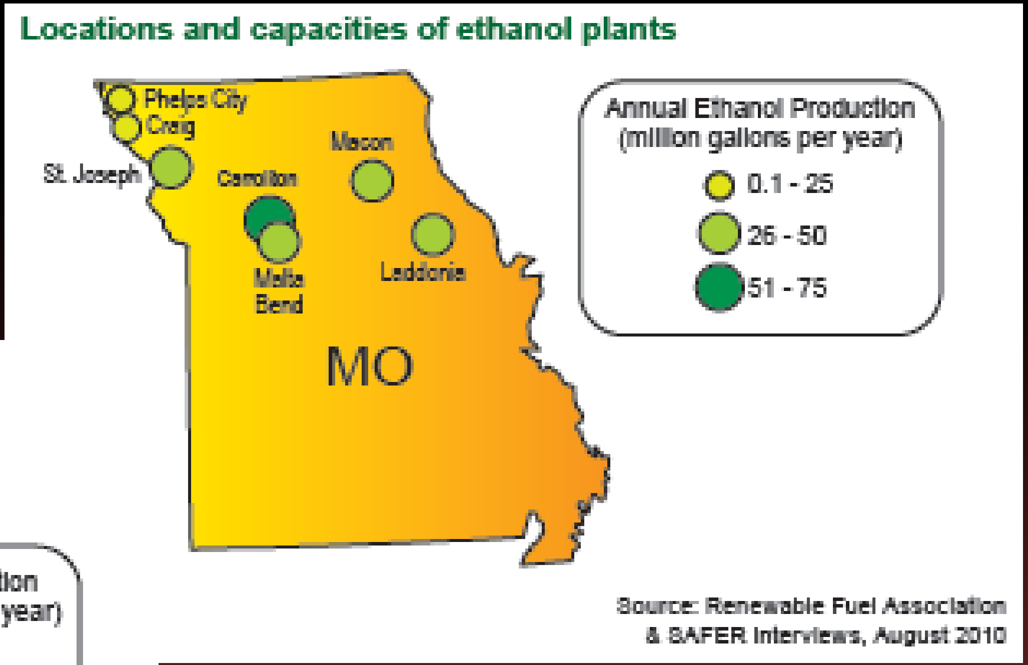
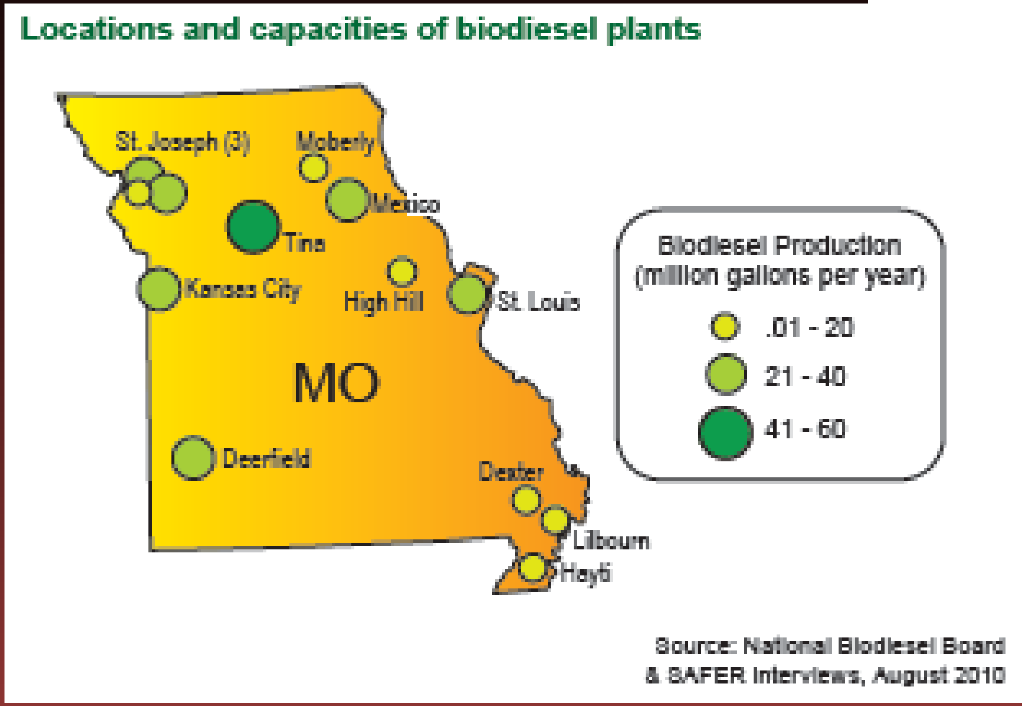




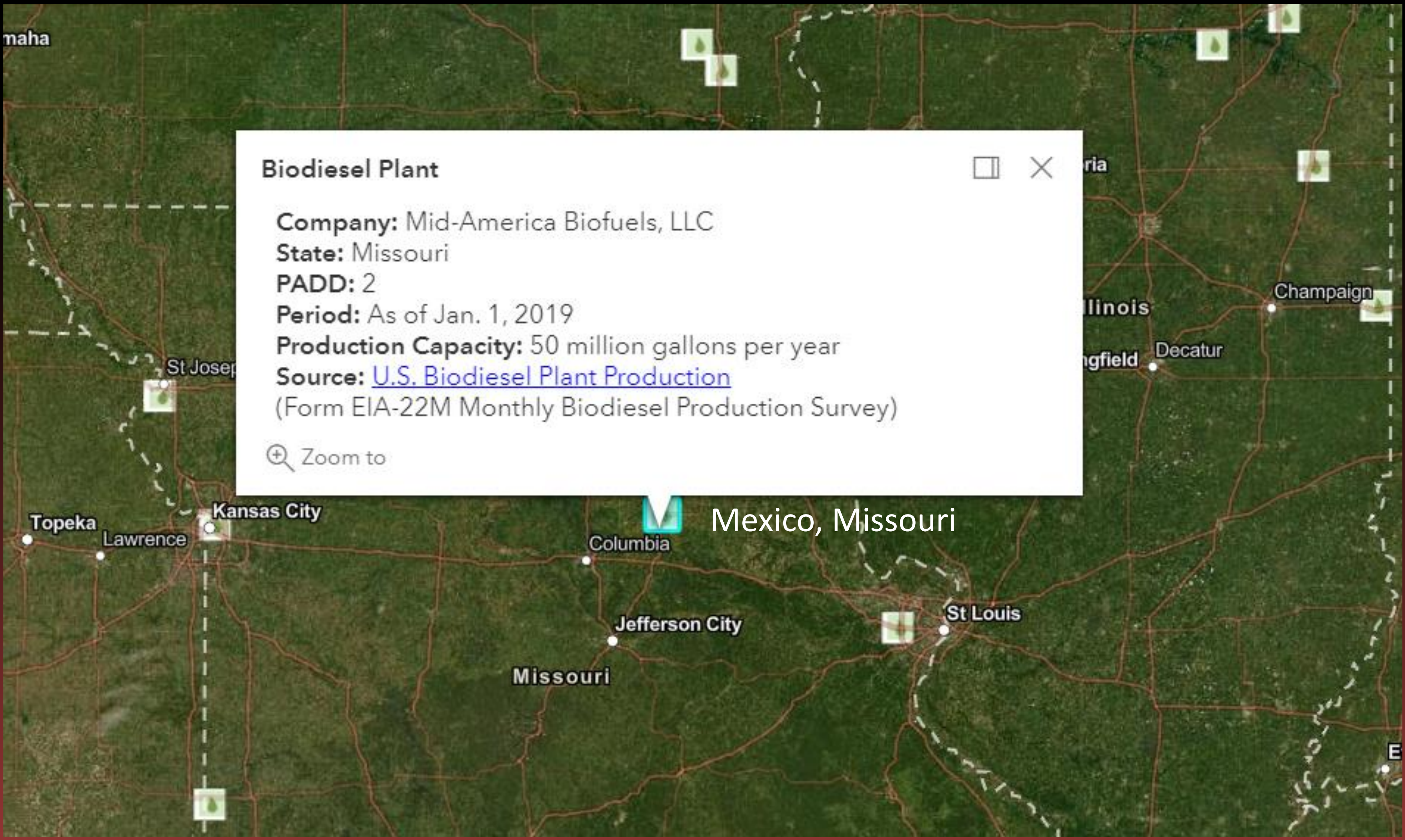
Biofuels Production

Source: Smith, J.D., et.al., "Assessment of Missouri's Biomass/bioenergy Industry," June (2012).

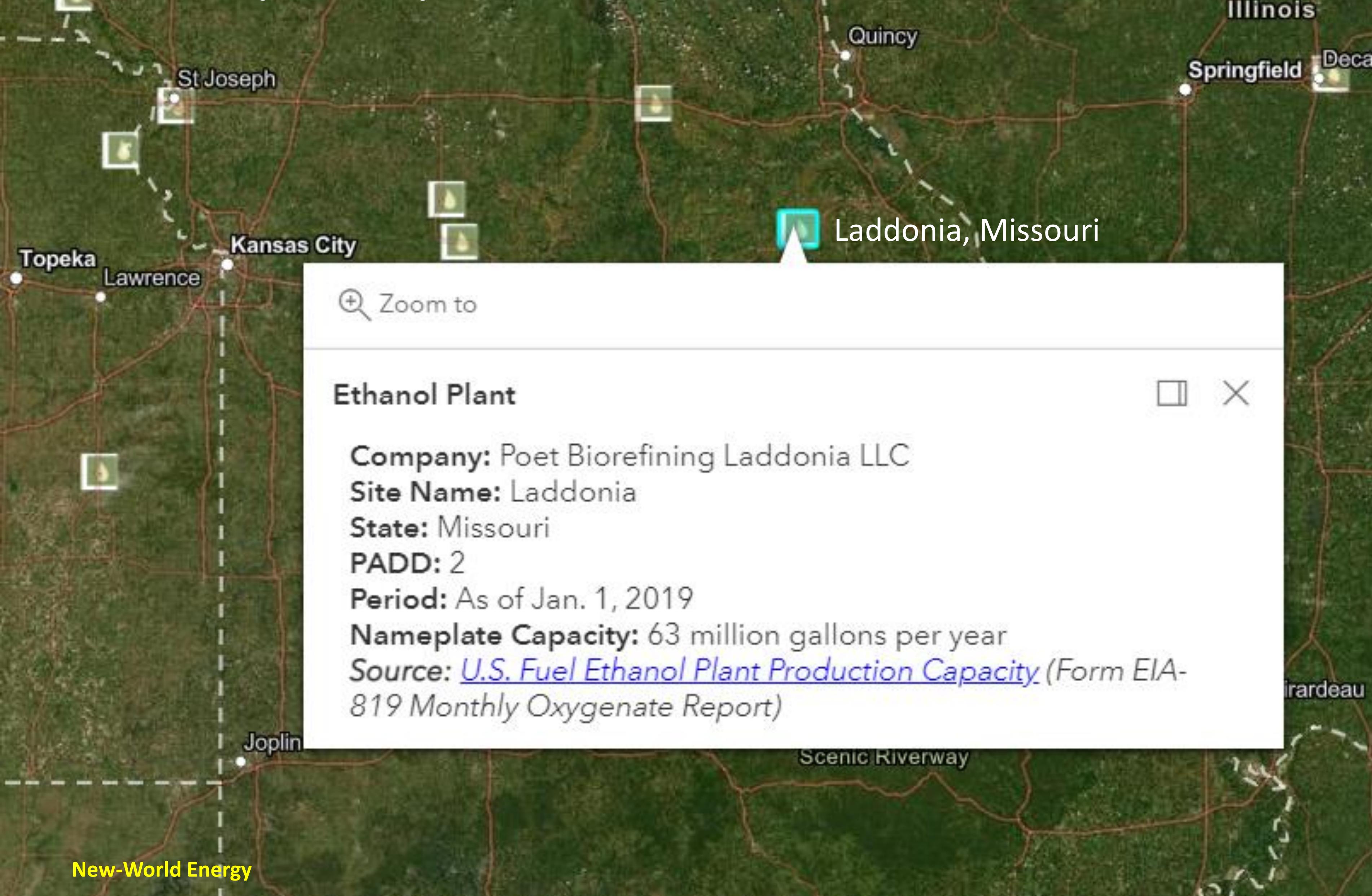




Cargill plant produces biodiesel from Soybeans

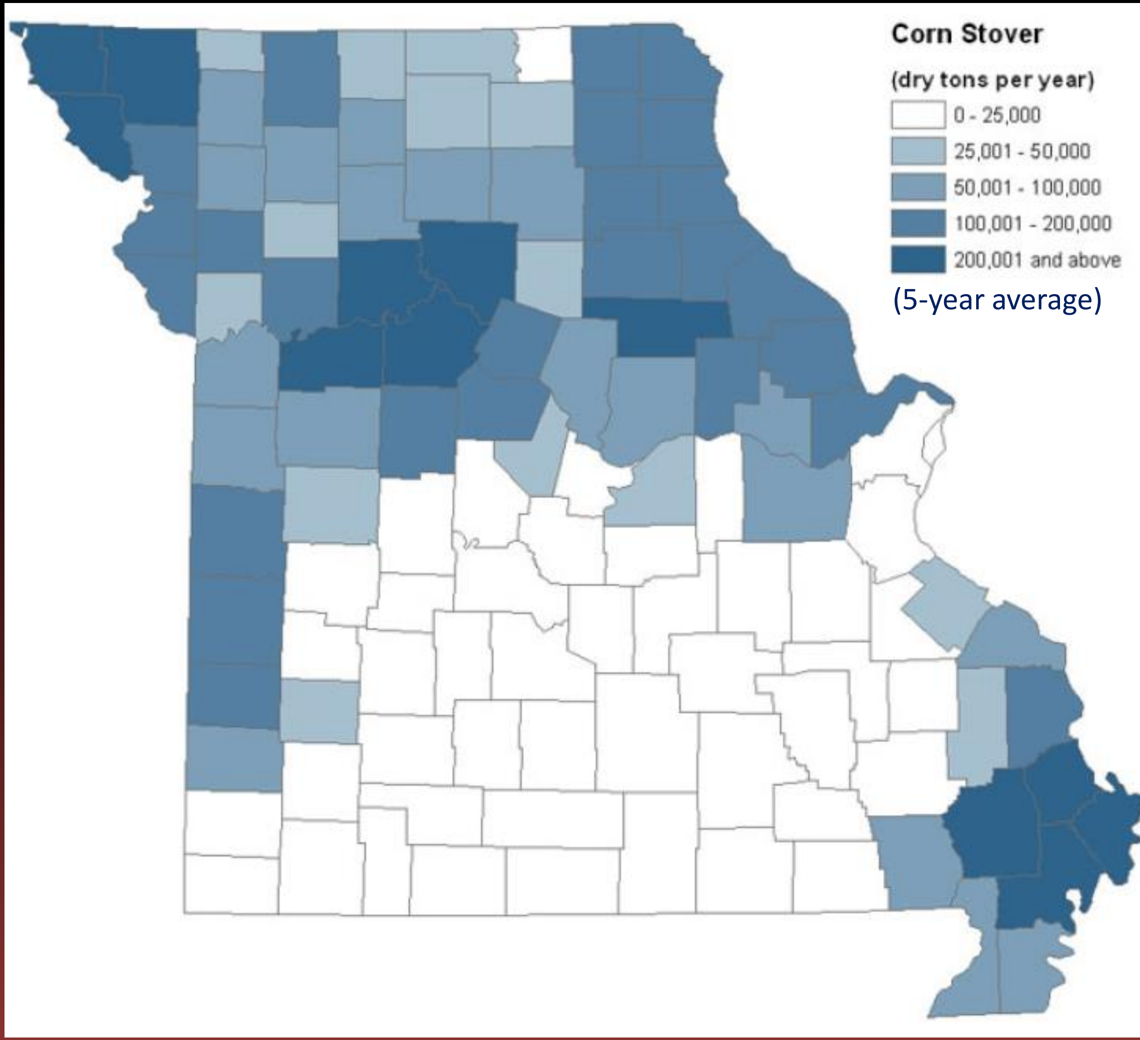


POET plant produces bioethanol from Corn



Potential Biomass Source for New Biofuels: Corn Stovers (residual left after harvest)

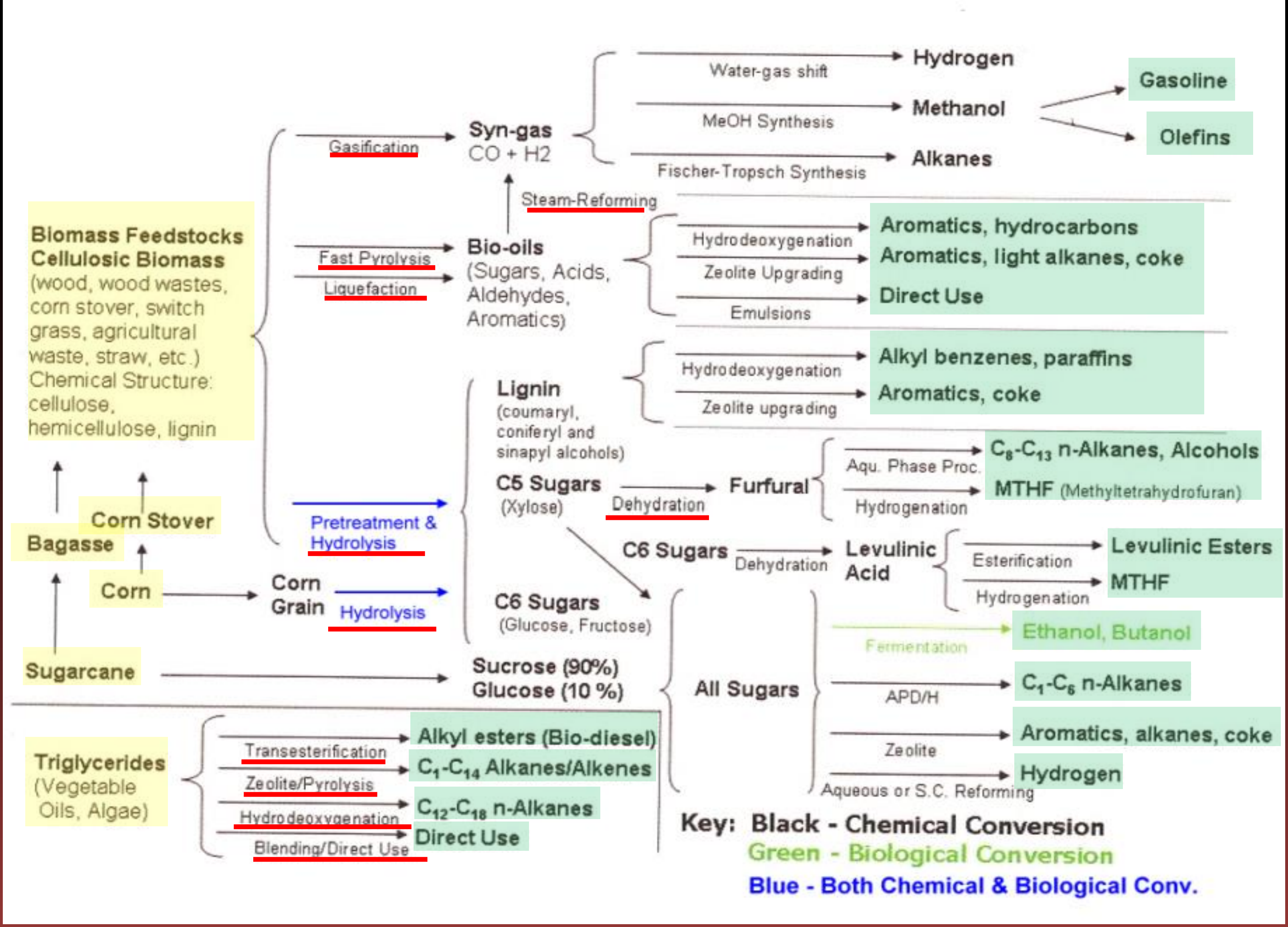
Source: Univ of Missouri Extension Service, "Feasibility of Corn Stover in Missouri," January (2011).



Typical composition:
- 38% cellulose
- 26% hemi-cellulose
- 19% lignin
- 6% ash
- HHV 7,487 Btu/lb (~Lignite coal)

Potential Challenges
- High alkaline content (fouling)
- Low bulk density (storage/transportation)
- High moisture content (~2x > grain)
- Short harvest window (wet stover spoilage)
- Impact on soil (leave some in field)

Biomass based Poly-generation uses diverse processing to increase System Resilience



Bio-oil from Gasification

Dry Biomass

↓

Flash pyrolysis

$T > 450\ ^0C$, $\tau < 1$ s,
heating rates > 1000 ^0C

↓

Liquid (bio-oil)
up to 70 mass %
to dry biomass

↓ H_2 catalysts

Upgraded bio–crude–oil

The main disadvantages of bio-oil:

- Very viscous
- Unstable (readily polymerized)
- Poorly evaporated
- Immiscible with ordinary fuels
- Strongly acidic (pH=3)

Because of high content of oxygen

Elemental composition:

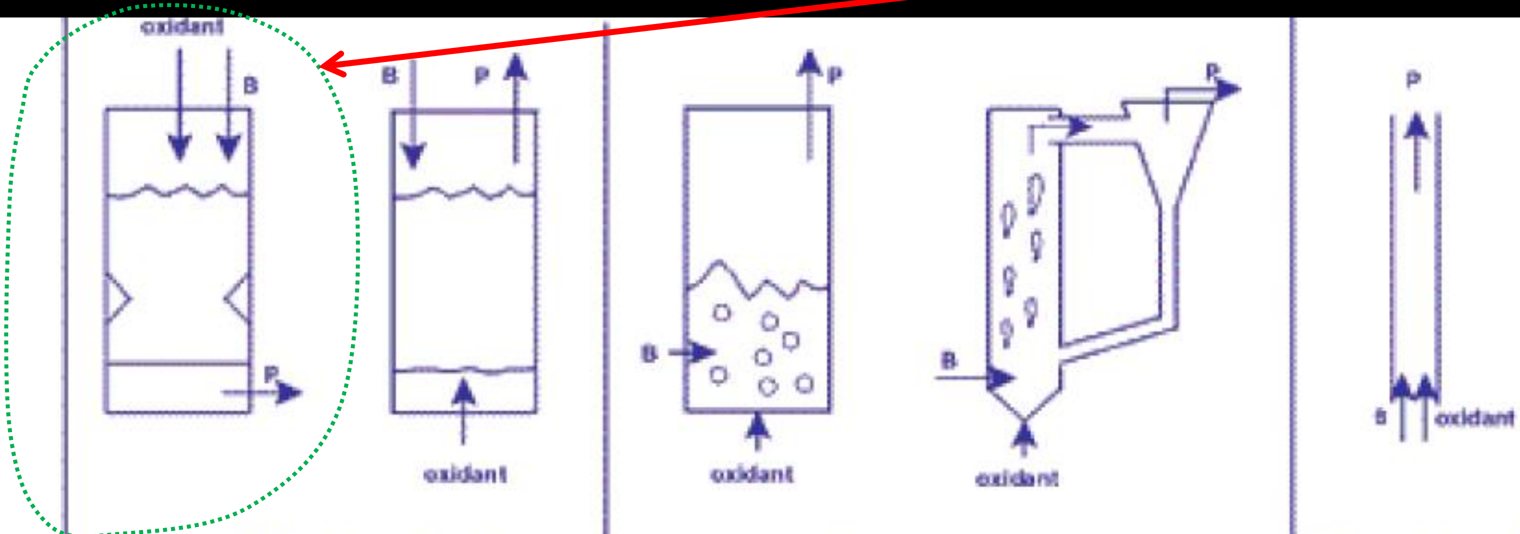
C – 30-60 %
O – 30-60 %
H – 6 - 7 %
N – <1 %

Up to 30 % of H_2O

so, bio-oil has to be upgraded in order to improve its quality as a fuel

Types of Gasifiers

S&T Downdraft Biomass Gasifier

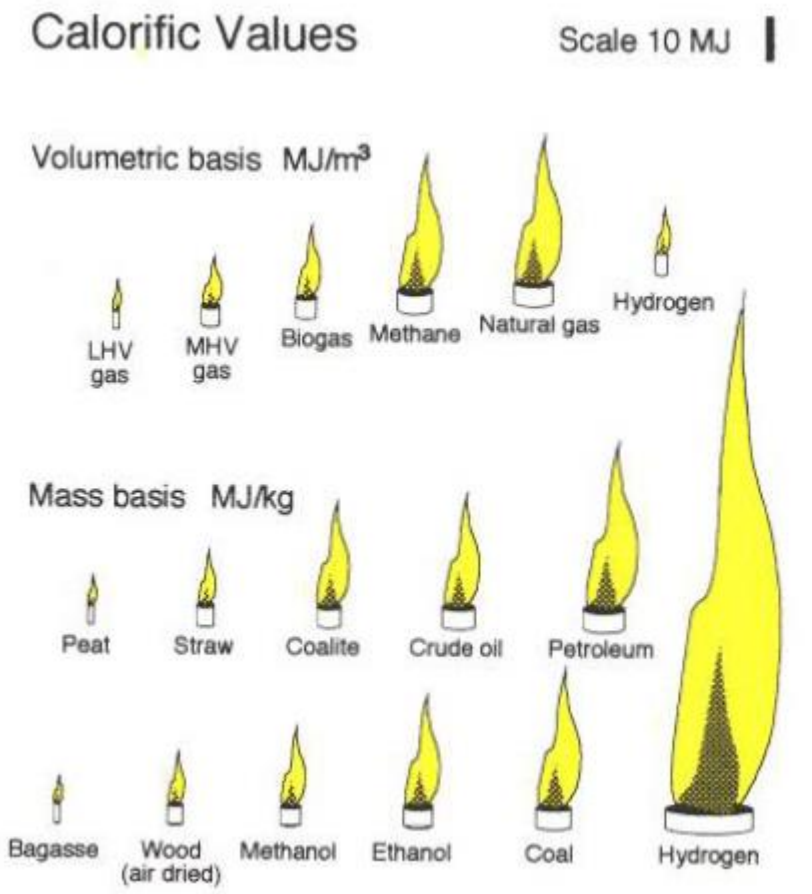


	Moving beds		Fluid beds		Entrained beds
	Co-current	Counter current	dense	circulating	
T°C	700-1200	700-900	< 900	< 900	[illegible]1500
tars	low	very high	intermediate	intermediate	absent
control	easy	very easy	intermediate	intermediate	very complex
scale	< 5 MW_t	< 20 M_t	10<MW_t<100	20<MW_t<?	> 100 MW_t
feedstock	very critical	critical	less critical	less critical	very fine particles

By-product of biomass gasification: Hydrogen

Applications

1. Energy resource
2. Oil refining. (The main problem of oil refinery – lack of hydrogen in the crude oil for light motor fuels production)
3. Motor bio-fuels production (hydrotreatment of bioliquid)
4. Other applications (instead electrolyzers in chemical industry and in other sectors of economy where hydrogen source with middle capacity (few kg/h) is needed



Hydrogen Required to Upgrade Biobased Fuels

FUEL	Bulk Density (kg/liter)	Mass Energy Density (MJ/kg)	Volume Energy Density (MJ/liter)
Softwood chips ("Denver dry", 7% MCWB)	0.19	20	3.8
Coconut shell (broken to ¼" pieces)	0.54	20.5	11.1
Sawdust pellets (¼") (Home Depot)	0.68	20	13.6
Peanut shell pellets (3/8")	0.65	19.8	12.9
Corn	0.76	19.1	14.5
Soybeans	0.77	21 (?)	16.2
Coal (bituminous)	1.1 (?)	32.5	35.7
Biodiesel	0.92	41.2	37.9
Diesel	0.88	45.7	40.2

Hydrogen Addition

Next Gen Bio-fuel: ETOH vs Butanol

1-carbon	Methanol
2-carbon	Ethanol
3-carbon	Propanol
4-carbon	**Butanol**
5-carbon	Pentanol

Butanol vs Ethanol

- Higher energy content: 110,000 Btu/gal vs 84,000 Btu/gal (gasoline 115,000 Btu/gal)
- Safer in "Hotter" regions: 6X less "evaporative" (13.5X less evaporative than gasoline)
- Shipped through existing fuel pipelines (ethanol transported via rail, barge or truck)
- Perfect Drop-in fuel replacement on gallon-to-gallon basis

Commercial Biomass Gasification

Current Technology

Gasifiers fed wood waste (i.e., forest waste, tree thinning, diseased trees from managing forests, etc.) and urban wastes (limbs & branches from storm damage + RDF)

Ground view of Operating Biomass Gasifier

Feedstocks for Biomass Gasifiers

Atlantic Power Corporation

https://www.atlanticpower.com/

Operating Biomass Gasifiers

PIEDMONT

Location:
Barnesville, Georgia

Fuel Type: Biomass

Total Megawatts: 55

Atlantic Interest: 100%

Net Megawatts: 55

Electricity Off-Taker:
Georgia Power
PPA Expiry: September 2032
S&P Credit Rating: A-

CADILLAC

Location: Cadillac, Michigan

Fuel Type: Biomass

Total Megawatts: 40

Atlantic Interest: 100%

Net Megawatts: 40

Electricity Off-Taker:
Consumers Energy
PPA Expiry: June 2028
S&P Credit Rating:
BBB+

ALLENDALE

Location:
Allendale, South Carolina

Fuel Type: Biomass

Total Megawatts: 20

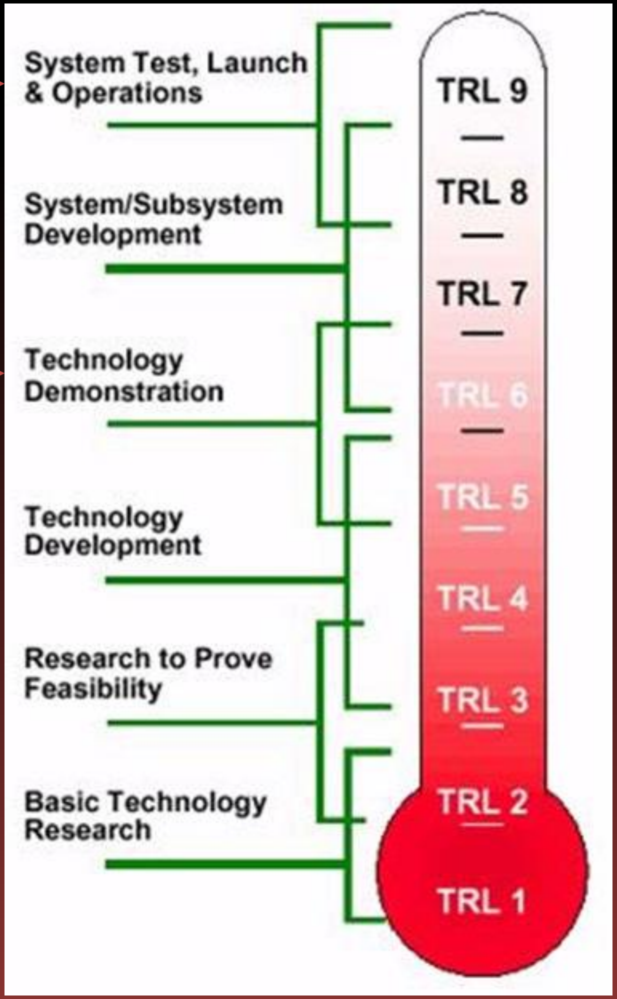
Atlantic Interest: 100%

Net Megawatts: 20

Electricity Off-Taker:
South Carolina Public Service Authority
PPA Expiry: November 2043
S&P Credit Rating:
A

Current Technology Readiness

- **Biofuels:**
  - Alternative (secure) source of transportation fuels
  - Current Technology: ETOH via anerobic digestion
  - Integrated energy system to generate next-gen biofuels
- **Technology maturity**
  - ETOH process/biorefinery: TRL = 9
  - Biomass Gasification TRL = 9
  - Next Gen Integrated Biofuels: TRL 5-7
- **Performance**
  - Current ETOH refinery fully scalable to 100,000 BPD
  - Current Pricing: $2/gal ETOH (corn price + fuel price)
  - Next Gen Biofuel Cost ($/gal Butanol) dependent on TRL



Biofuels Improves Energy Resiliency by providing additional energy source

- Technology is sustainable (economically and environmentally)
  - Renewable resource available in large regions of US
  - Detailed Design w/ Life Cycle Assessment (LCA) used to evaluate water use and GHG emissions from overall process
- Many Benefits for Biofuel Use
  - Reduced dependence on foreign crude oil
  - Reduced Carbon emissions
  - Improved Economic Performance with integrated production
- Potential Risks for Biofuel Use
  - Are we burning our Food? (use "Next Gen" Biofuels)
  - Biogenic Emissions? (perform detailed LCA to assess potential)
  - Unexpected impacts? (i.e., Dead zone in Gulf of Mexico)
- Conclusion
  - Next Gen Biofuels via integrated systems is sustainable and should be part of the New World Energy Infrastructure

Hybridization Improves Performance

Compare Normal Fuel Production to Integrated Fuels/Power Generation

Table 8. Overall process yields and efficiencies.

Product	Base Case	Mature Ethanol-Rankine	Mature Ethanol-GTCC
Ethanol			
(L/Mg)	318.0	439.5	439.5
(gal/dry ton)	76.2	105.3	105.3
(million gallons/year)	133.4	184.3	184.3
(% feed LHV)	40.4%	**54.1%**	54.1%
Net power			
(MW)	11.5	66.3	126.4
(% feed LHV)	3.5%	7.4%	14.0%
Overall efficiency	43.3%	61.5%	68.1%
(% feed LHV)			

Base Case:

- Fermentation to Produce ETOH

ETOH/Rankine Heat Recovery:

- Fermentation to Produce ETOH
- Biowaste burned in Circulating Fluid Bed Combustor /heat recovery

ETOH/GTCC to Produce Electricity:

- Fermentation to Produce ETOH
- Gasify Biowaste / syngas fed to Gas Turbine for electricity generation

Source: Laser, M., Haiming, J., Kemantha J., Lee R. L. "Coproduction of Ethanol and Power from Switchgrass", *Biofuels, Bioprod. Bioref.* 3:195–218 (2009).

Operations Comparison:
Standard vs Hybrid Performance

Table 16. Summary of yields, rates, and conversion costs.

	Base Case	Mature EtOH-Rankine	Mature EtOH-GTCC
Feedstock rate (dry Mg/day)	4535	4535	4535
Ethanol yield (L/dry Mg feedstock)	318.0	439.5	439.5
Ethanol production (MM gal/year)	133.3	184.3	184.3
Total installed equipment cost (MM $)	346.8	209.8	289.0
Total project investment (MM $)	603.8	359.1	532.6
Non-feedstock raw materials (MM $/yr)	30.8	9.4	9.4
Waste disposal (MM $/yr)	5.9	1.6	1.6
Exported electricity (MW)	11.5	66.3	126.4
Minimum ethanol selling price ($/gal)	$1.71	$0.73	$0.77

Same Feedrate

More Product

Less Investment

Less Waste

More Product

Lower Cost

Plant scale = 4535 dry Mg feedstock/day

Feedstock price = $49/Mg

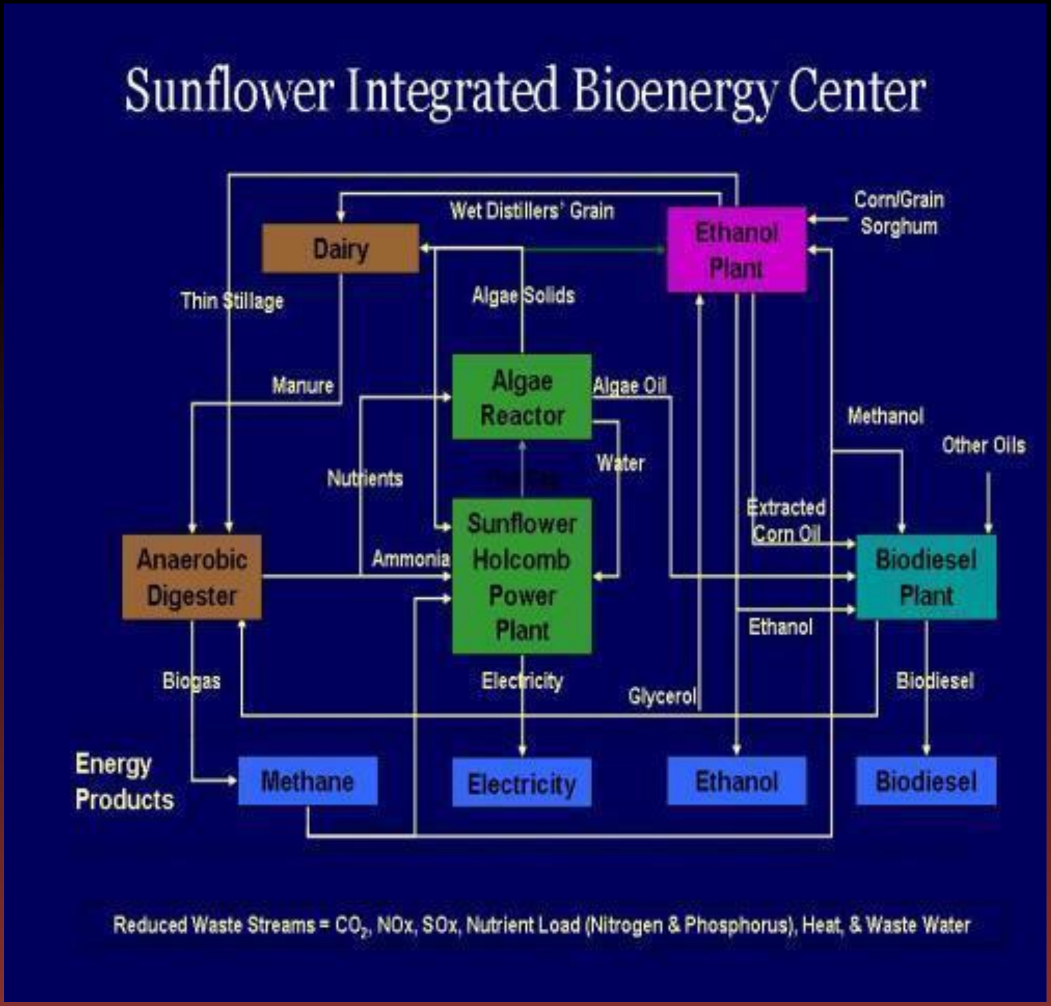
Electricity price = $0.05/kWh.

Online time = 8400 hours/year.

Source: Laser, M., Haiming, J., Kemantha J., Lee R. L. "Coproduction of Ethanol and Power from Switchgrass", *Biofuels, Bioprod. Bioref.* 3:195–218 (2009).

"Integrated" System using All available energy resources

- Combine conventional + alternative energy sources
- Sunflower Integrated Example
  - Increased efficiency
  - Better economics
  - Poly generation of electricity, liquid fuels and chemicals
- Current work on:
  - Integrating wind/solar with fossil and nuclear energy
  - System analysis and testing at S&T Hybrid Energy Lab



Small modular nuclear reactors support resilient systems

Small means <300 MW electric (< 1000 MW thermal)
5 - 25% generating capacity of conventional light water reactors

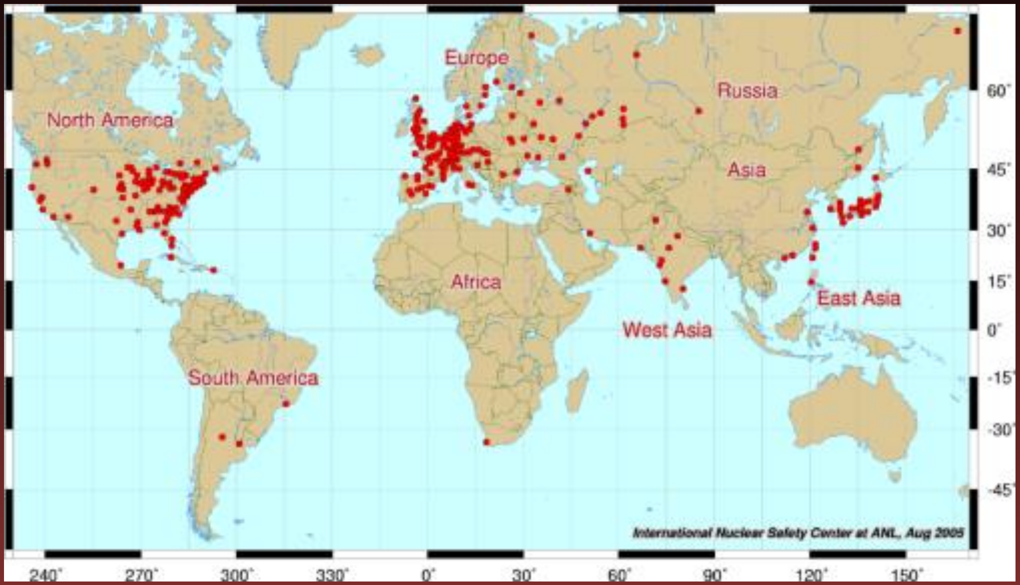
Better match to scale of methanol and ammonia processes

Similar capacity as current wind farms to mitigate intermittent generation

Lower capital cost makes project financing less risky

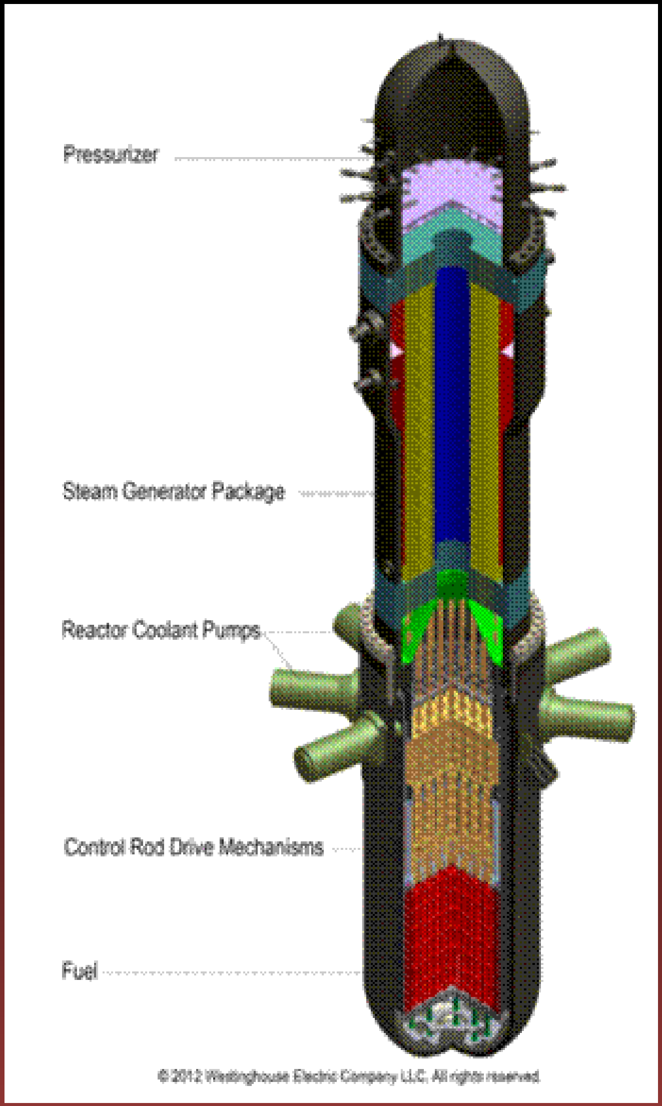
Used where demand is modest or transmission capacity limited

Can be located on smaller bodies of water (for cooling)



Nuclear power reactor locations. Figure from International Nuclear Safety Center, www.insc.anl.gov

Use Small Modular Reactor's to meet Local Power Needs

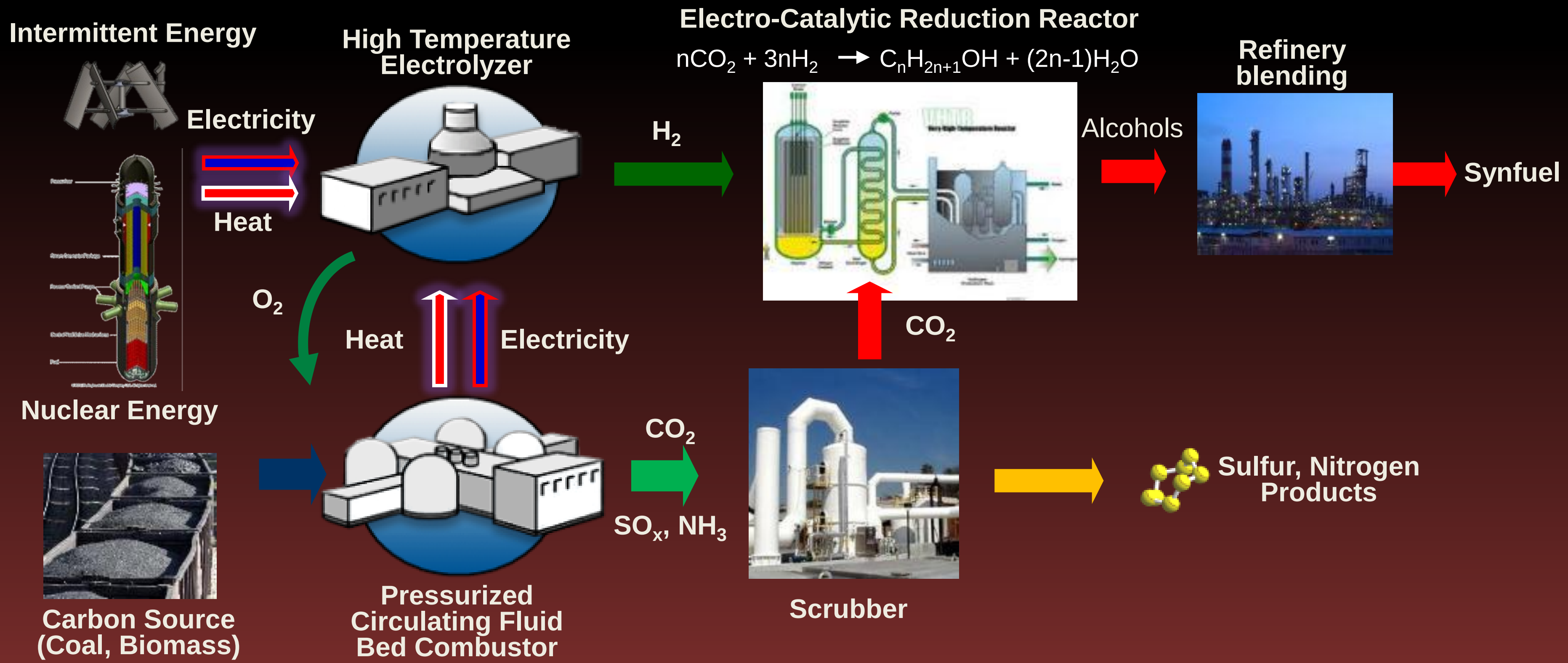


Current SMR Designs

Potential SMR Designs for Army	Power Rating (MWe)	Licensee Applicant
NuScale	45	NuScale Power + Flour
B&W mPower	150-180	Babcock & Wilcox
W-SMR Integral Reactor	200	Westinghouse Electric
Power Reactor Innovative Small Module (PRISM)	311	GE-Hitachi

Next Generation Load Following Energy System to Produces Liquid Fuels from CO2

- **Integrate renewable intermittent energy (i.e., wind, solar, etc.) with "load following" smart system**
- **Electrolyzer uses CO2 from PCFB reactor**

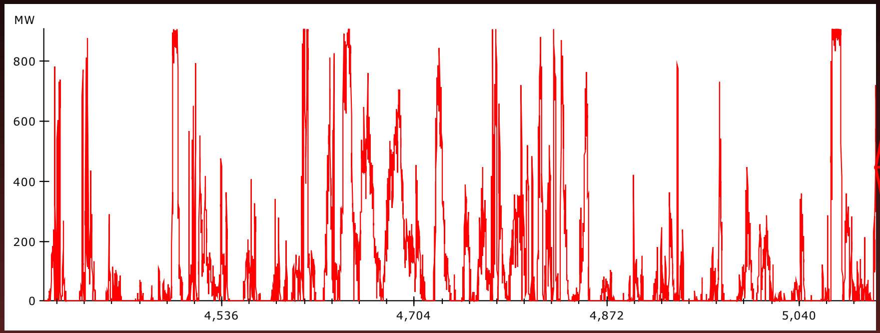


- Hybrid system uses much less carbon resource
- Flexible PCFB system produces pure CO2 stream that is converted to liquid fuels/chemicals
- Sulfur, Urea by-products
- Ultra low emissions (NOx, CO, PM, Hg)

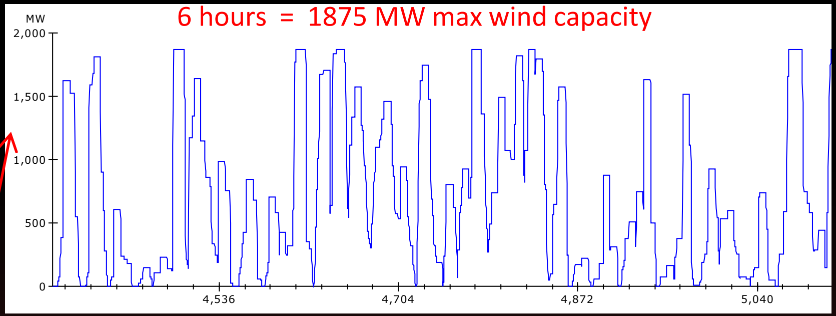
Nuclear Hybrid integrates wind fluctuations by generating H2/O2 via Electrolysis

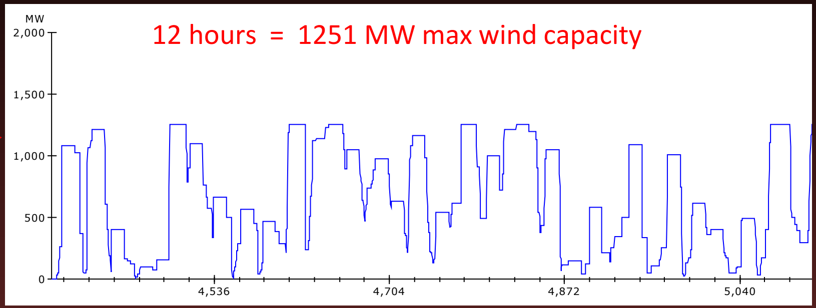
Use Load following SMR reactor

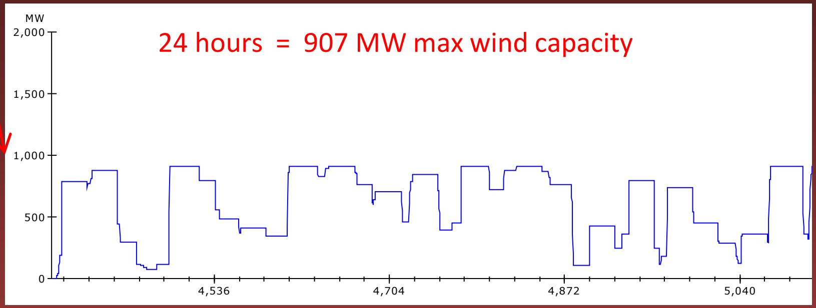
Fixed oxygen availability means
- Fixed total annual MWhr of compensation
- Fixed annual fuel usage



Single site 30% wind power profile in Wyoming in July (NREL)



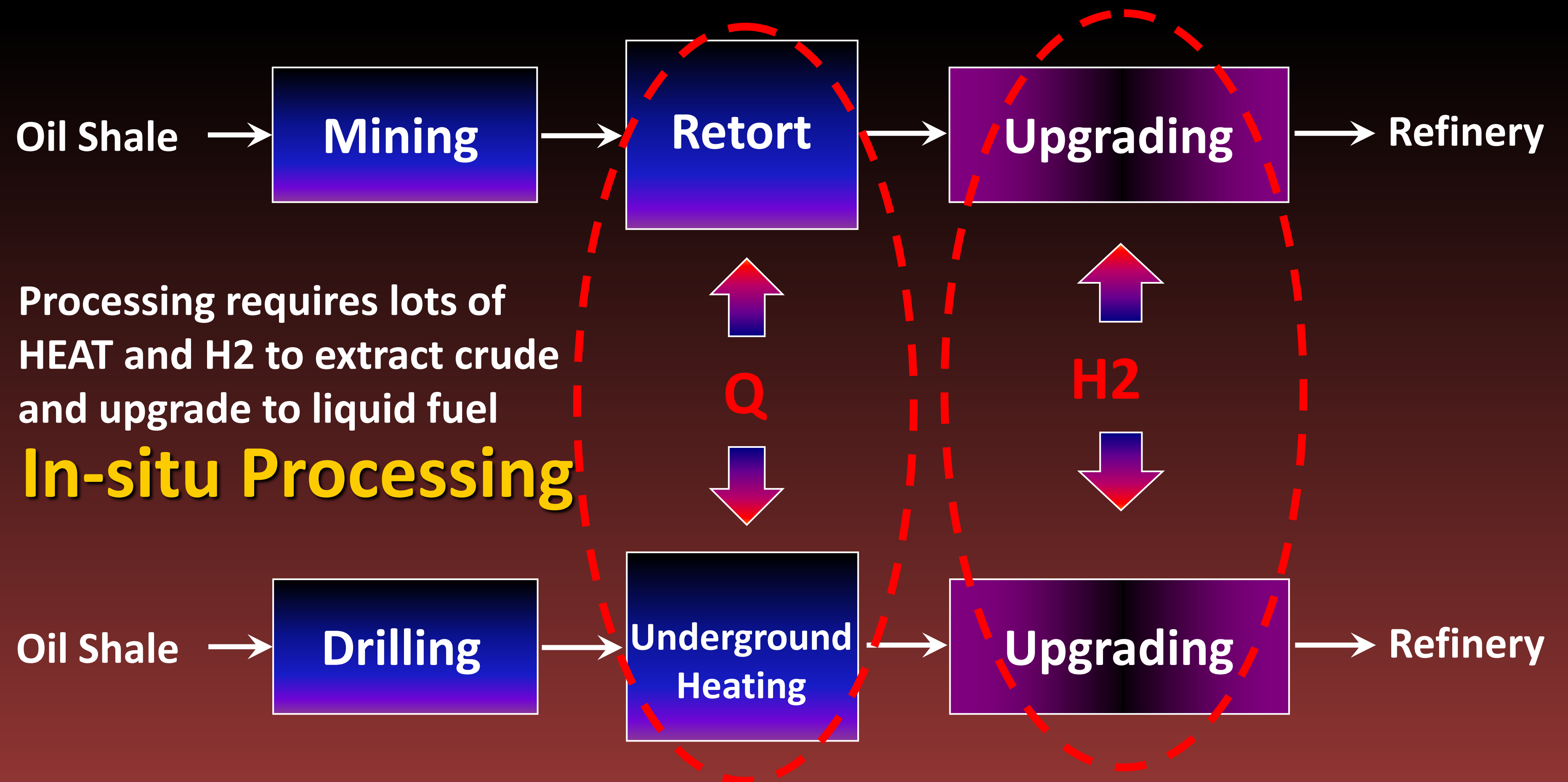




By storing wind energy as chemical energy, intermittent fluctuations reduced

SMR can support development of Unconventional Fuels

Surface Processing

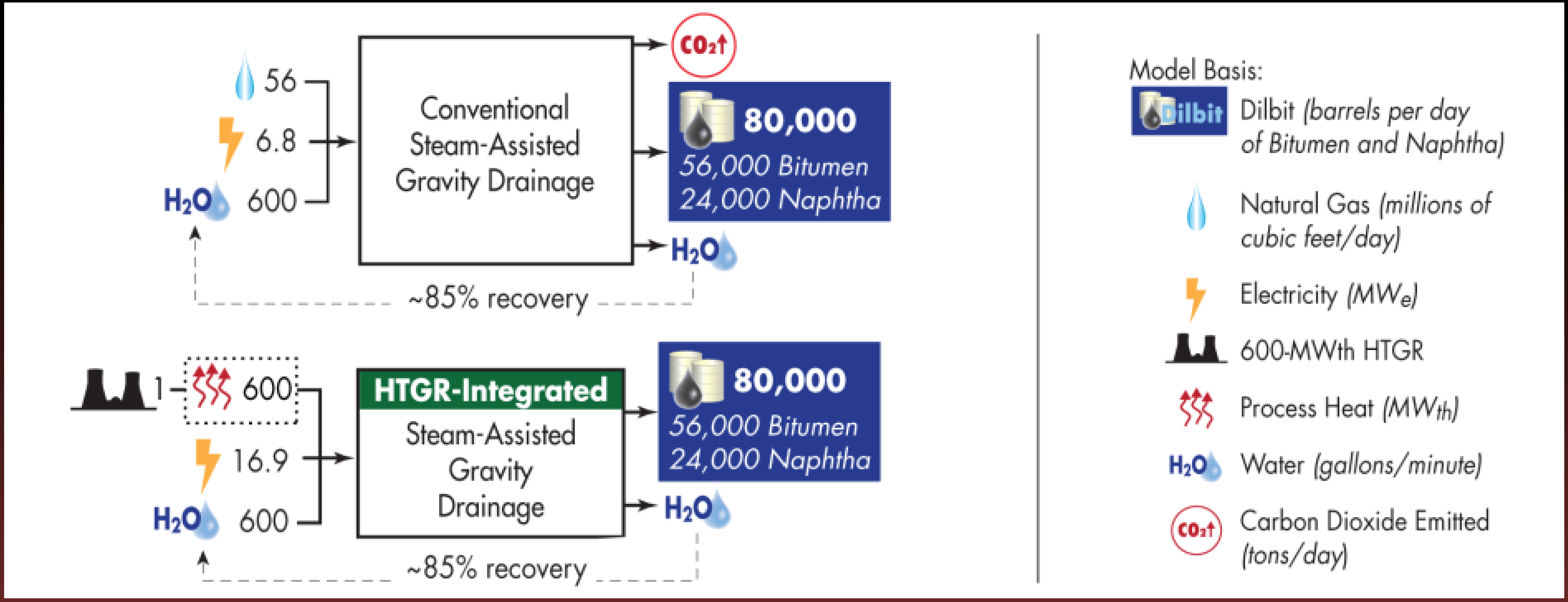


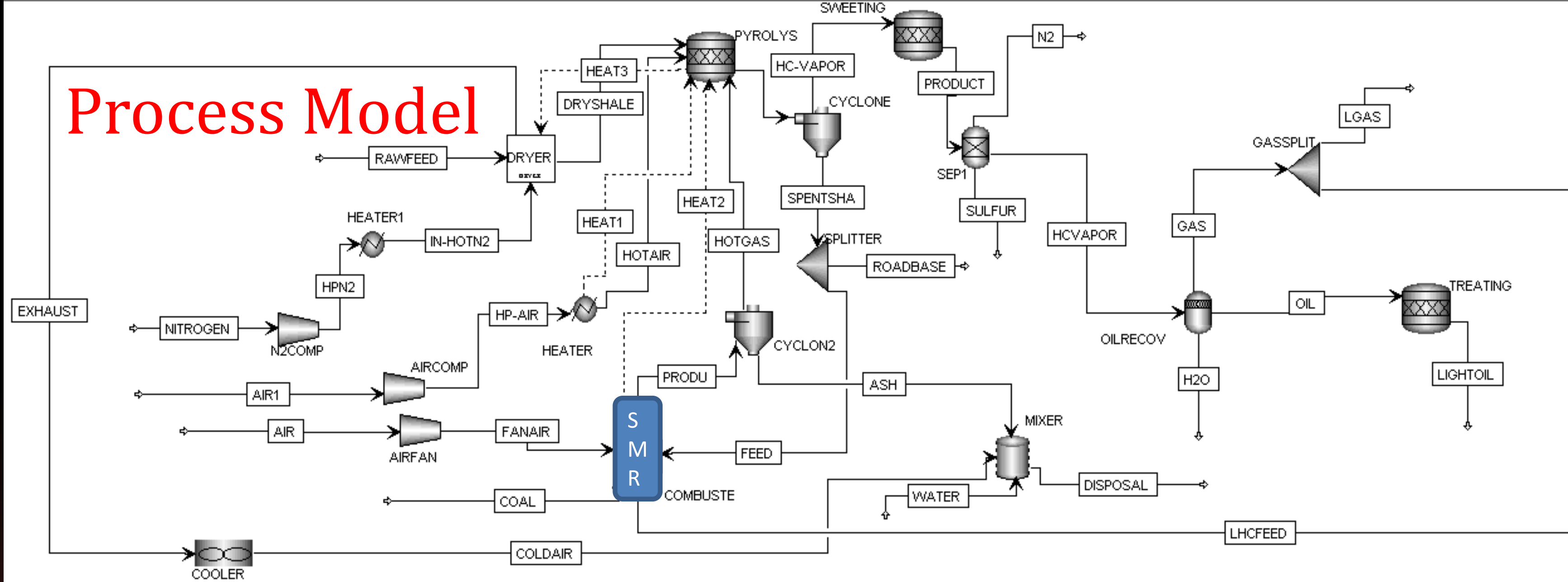
Processing requires lots of HEAT and H2 to extract crude and upgrade to liquid fuel

In-situ Processing

Process Modeling Results - SAGD

Nuclear Hybrid reduces NG consumption and eliminates CO_2 emissions





Light Oil After Refinery Treatment	Shale Oil	High Bed Temp Spent Oil Shale	Low Bed Temp Spent Oil Shale	Crushed Raw Oil Shale

Nuclear Hybrid to Produce Crude Oil from Shale

- **Particle size**: Increase surface area w/ smaller particles
- **Bed Mixing**: Use bed lifters to increase bed HT/MT
- **Bed Rotation**: Between 0 - 20 rpm (increase HT and res time)
- **Carrier Gas**: Super heated steam, N2, CO2 or none
- **Particle heating/reactor cleaning**: Mix metal spheres w/ feed oil shale

Wrap up

- **Current energy status**
  - Secure Energy is this generation's "Grand Challenge"
  - Resilient Energy significant component of National Security
  - DOD energy mission: **Reduce Demand, Increase Efficiency, Find Alternative Sources, and Create Culture of Energy Accountability while Sustaining or Enhancing Operational Capabilities**
  - Resilience refers to "Useful Energy" and not just "How much" you have
  - Resiliency metrics: Surety, Survivability, Supply, Sufficiency and Sustainability
- **Biofuels Part of New World Energy**
  - Significant amount (diverse resources) available for biofuels
  - Bio-chem + Therma-chem processes (combined digester/gasification development)
  - Hydrogen required to upgrade biofuels
  - Biomass gasifier coupled with SMR and Wind/Solar Energy can provide hydrogen
- **Technical merit**
  - TRL ~9 for biomass gasification (research required for integrated system)
  - Nuclear hybrid technically feasible to reduce CO_2 emissions via HTCE
  - SMR applicable for industrial and military applications
  - Nuclear Hybrid can sustainably recover unconventional hydrocarbons
- **Economic viability**
  - Example showed integrated energy system has higher economic performance

Questions?

Biofuels Transformational for Resilient Society (generated locally)

Feedstocks

- Cost
- Quality
- Availability
- Location

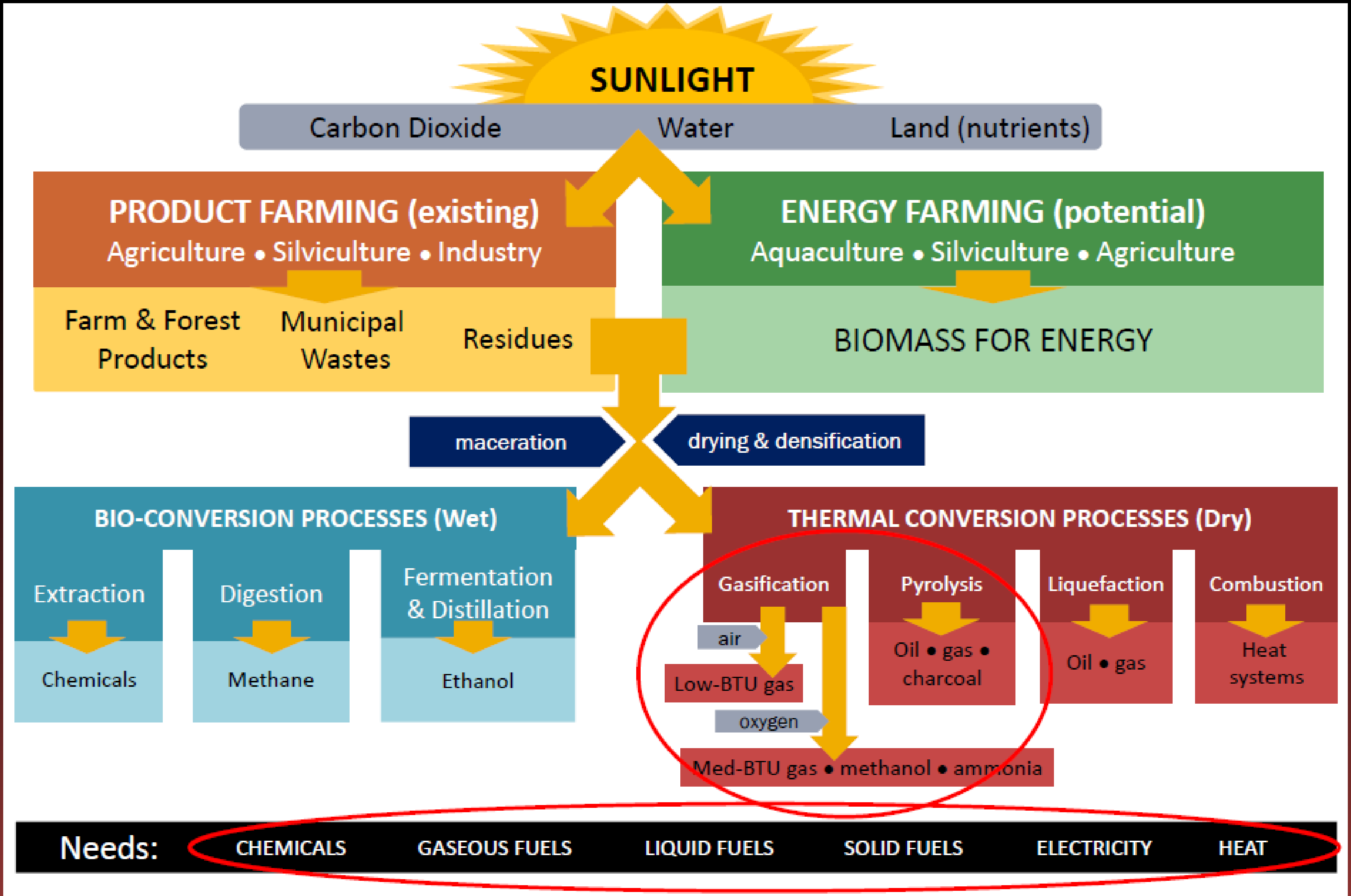
Technologies

- Status
- Capital cost
- Operating costs
- Yield
- Efficiency
- Scale
- By-products

Products

- Value
- Demand
- Competing routes
- Quality specs
- Green credits

Transformation Paths for Biomass Use



Army Energy Security Implementation Strategy

K. Geiss, Program Director, Energy Security, “Army Energy Security”, Society of American Military Engineers, 20 May (2009).

Energy Security Vision: enhance and ensure mission success and quality of life for soldiers, their families, and civilians through leadership, partnership, and ownership, and serves as model for nation

Energy Security Mission: reduce demand, increase efficiency, seek alternative sources, and create culture of energy accountability while sustaining or enhancing operational capabilities

Strategic Goals:

1. **Reduce Energy Consumption**
2. **Increase Energy Efficiency across platforms and facilities**
3. **Increase use of renewable/alternative energy**
4. **Assure access to sufficient energy supplies**
5. **Reduce adverse impacts on the environment**

Army's Energy Security Characteristics

Energy Security

K. Geiss, Program Director, Energy Security, "Army Energy Security", Society of American Military Engineers, 20 May (2009).

- **Surety, Survivability, Supply, Sufficiency, Sustainability**

  - The Core Characteristics defining the ***Energy Security*** necessary for the full range of Army missions.

Surety: Preventing loss of access to power & fuel sources

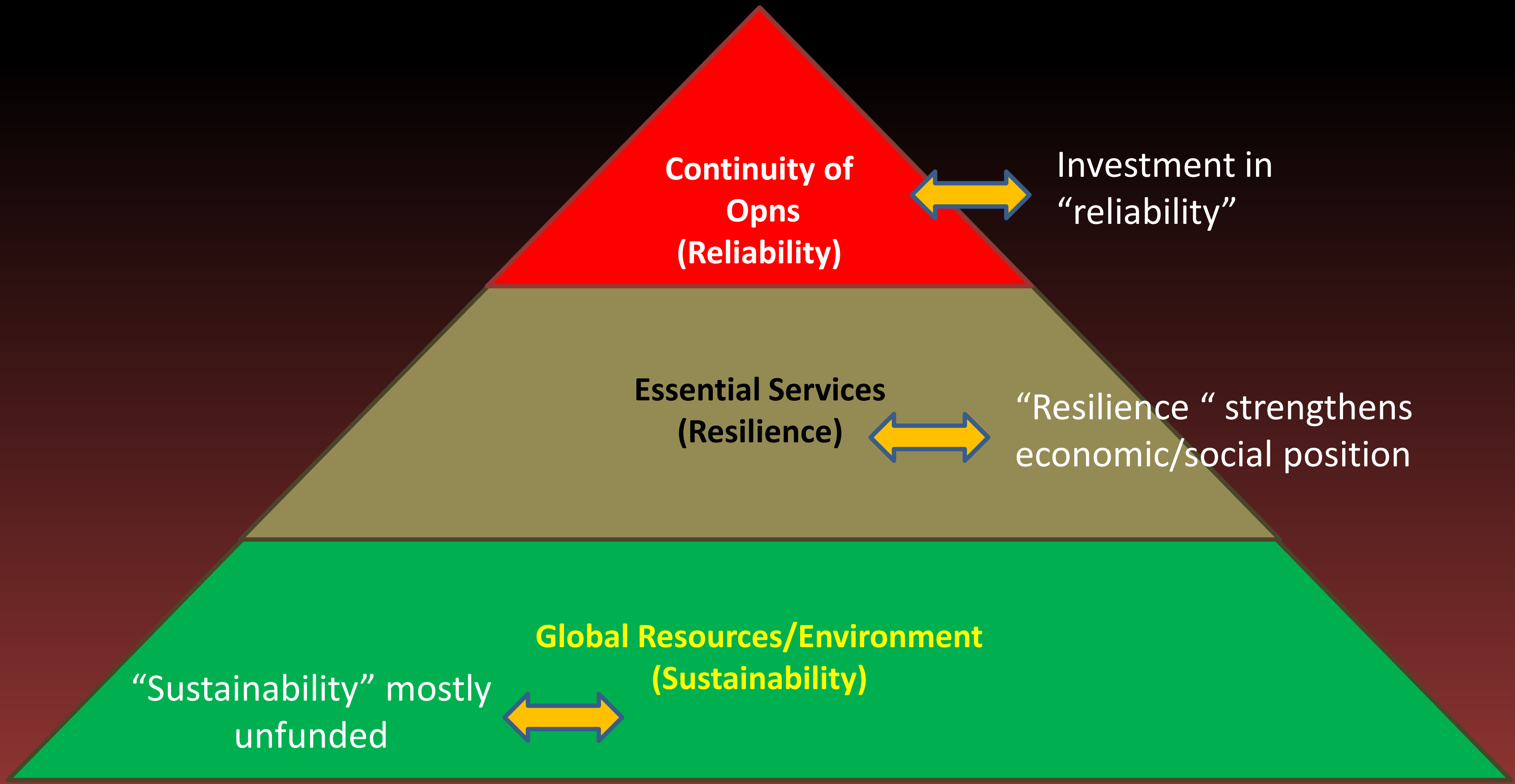
Survivability: Ensuring resilience in energy systems

Supply: Accessing alternative & renewable energy sources available on installations

Sufficiency: Providing adequate power for critical missions

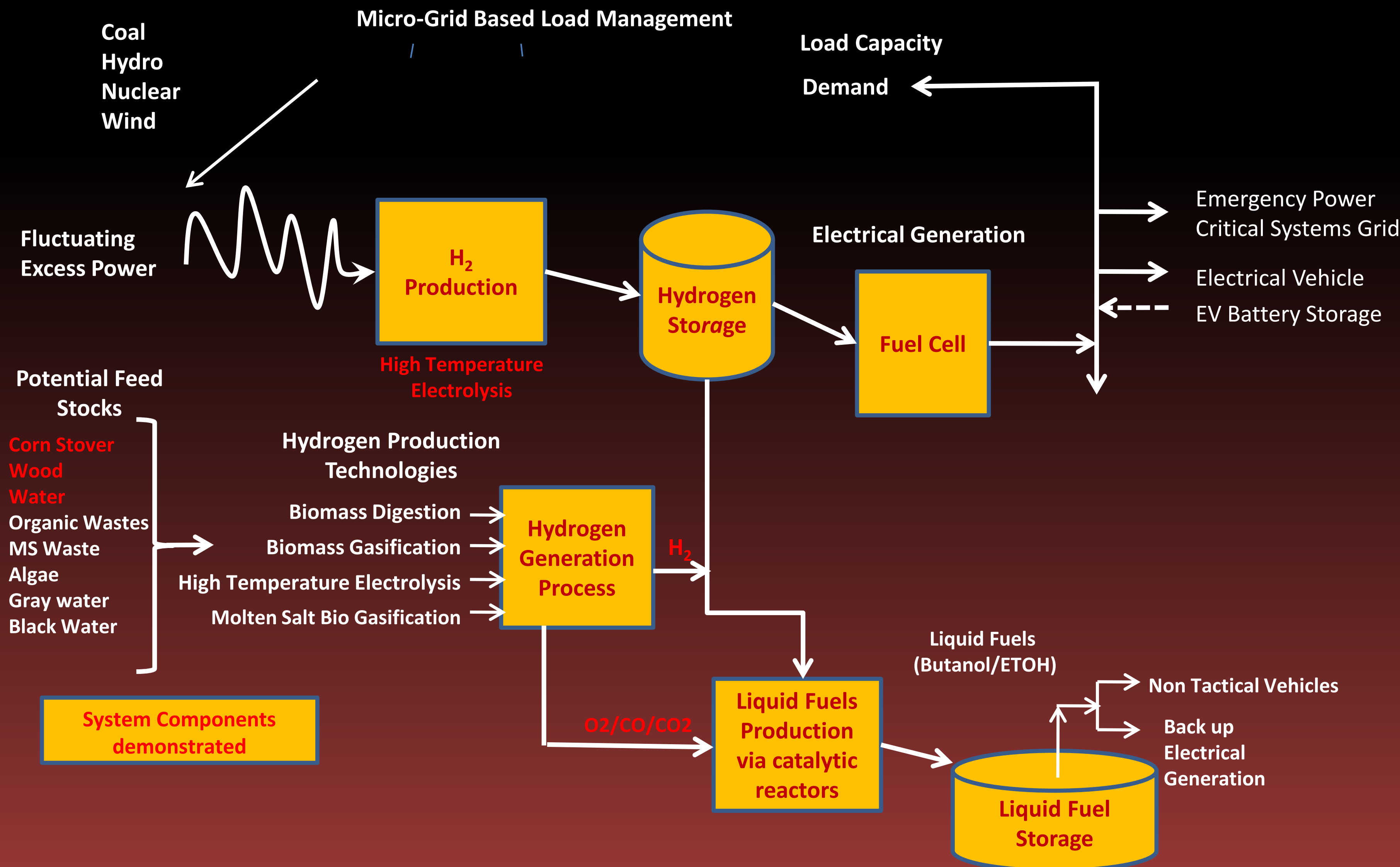
Sustainability: Promoting support for the Army's mission, its community, and the environment

Energy more than "how much?"

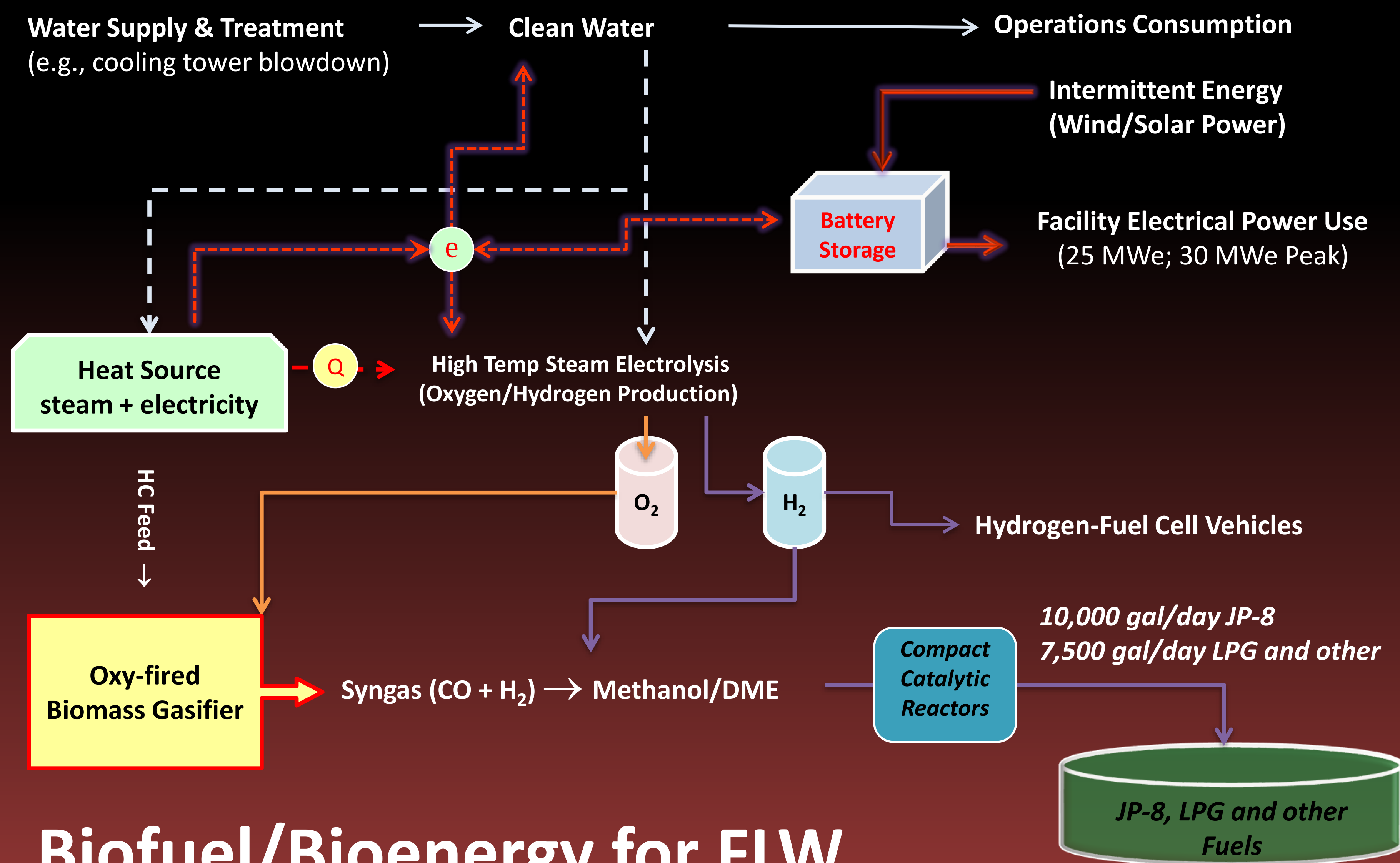


Next Generation Energy System uses all available resources

Integrated Energy Study at JBLM

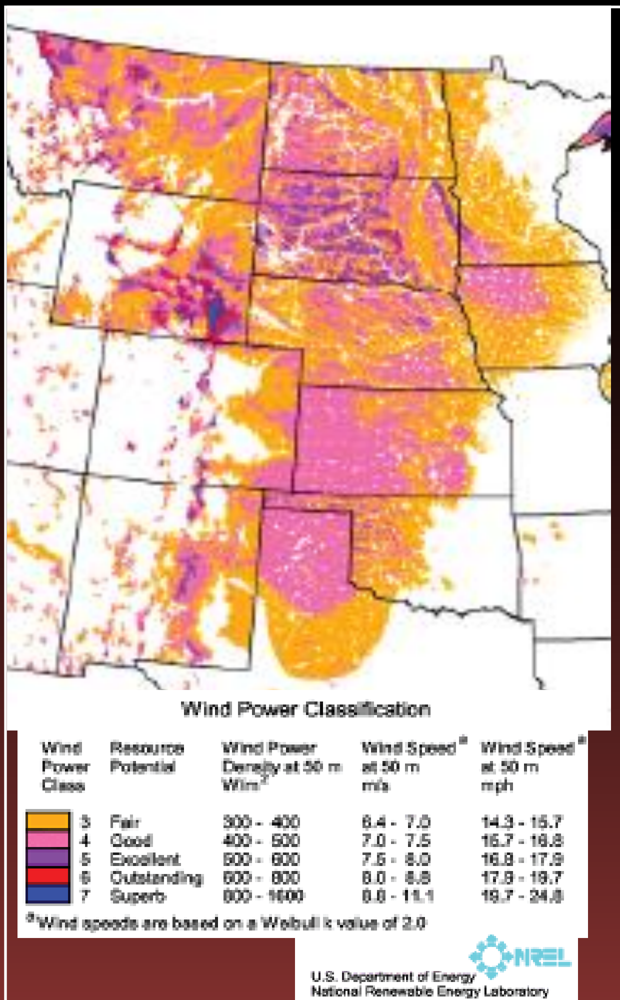


Next Generation Energy System uses all available resources

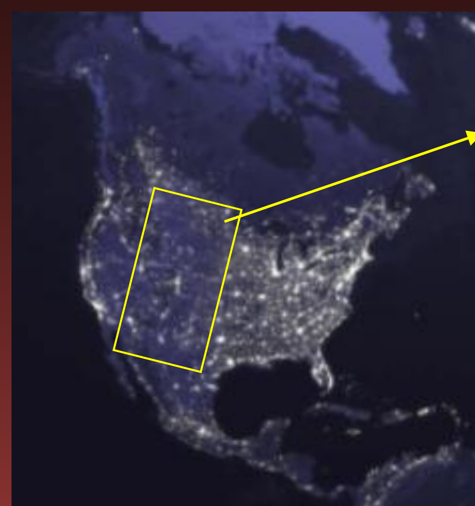


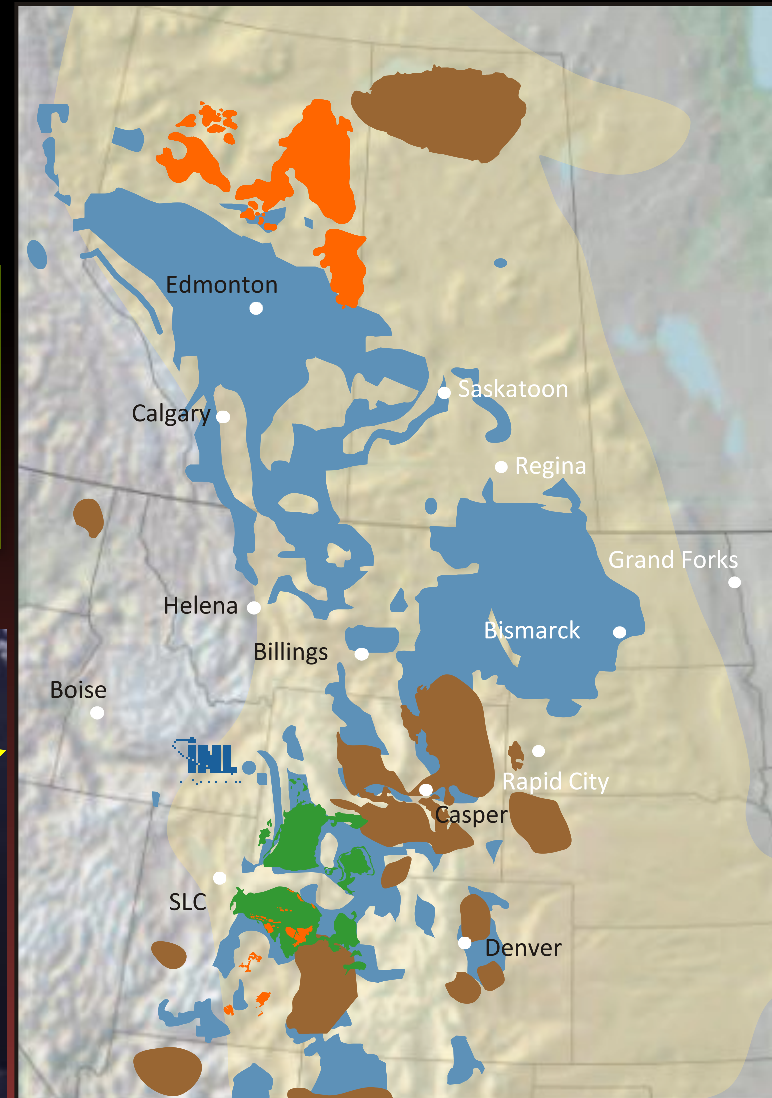
Biofuel/Bioenergy for FLW

Tapping Western Strategic Energy Resources



Western Energy Corridor contains strategic resources to meet America's energy security challenges





Oil shale
Oil sands
Uranium
Coal basins