Industrial load flexibility, the US power grid and ammonia

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Ammonia Energy Conference

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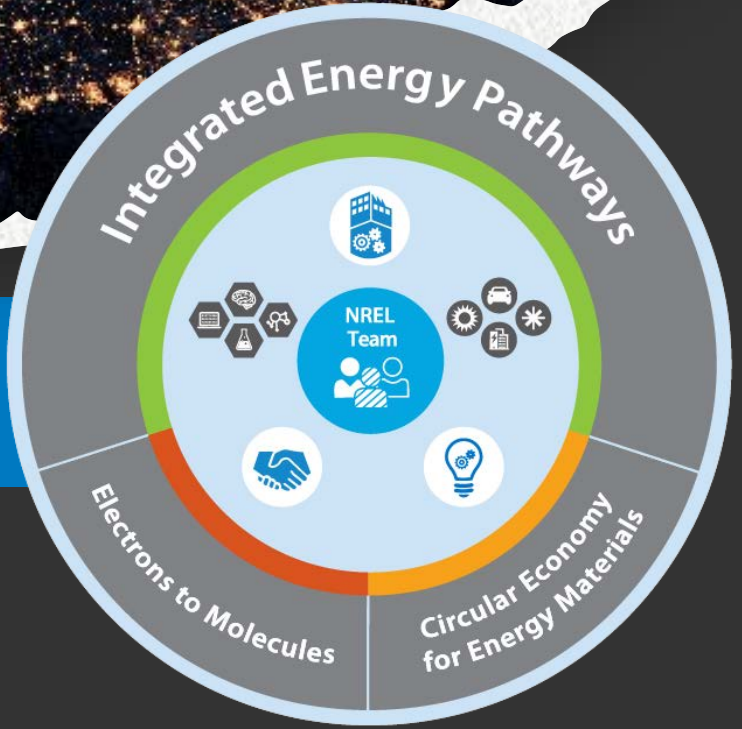
NREL Vision

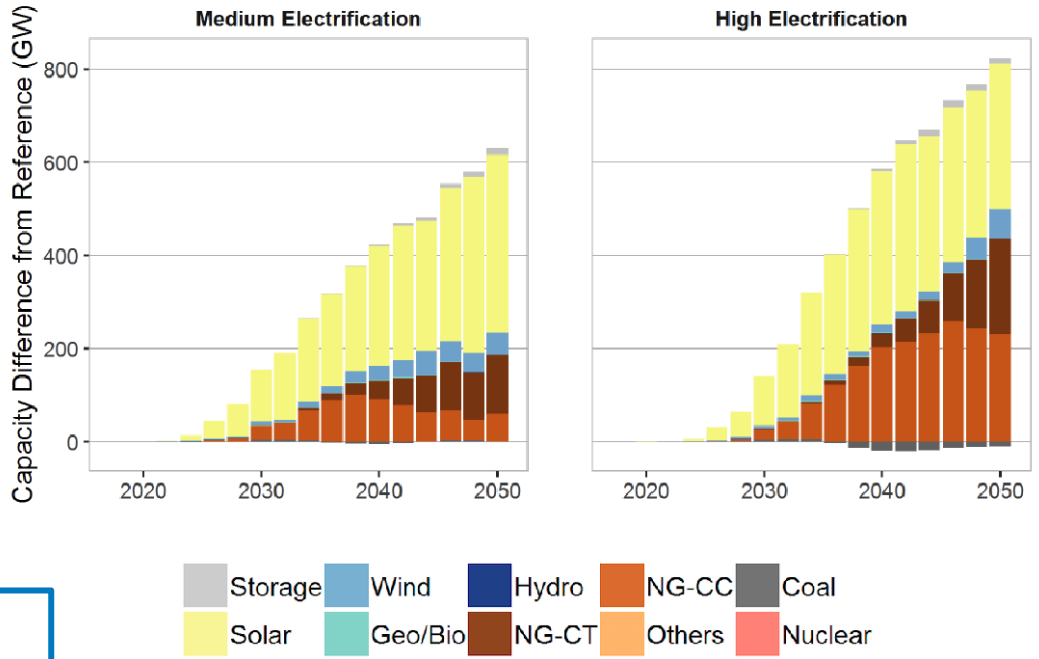
A clean energy future for the world



Flexible Loads in Context

- Variability in power supply changes grid characteristics (FERC, 2021)
  - Reserves & flexibility more important
- Electrification requires more generation capacity
  - Demand response frequently cheapest option

The combination of renewable energy transition and electrification makes flexible demand especially beneficial… but where is it and how can it be deployed?

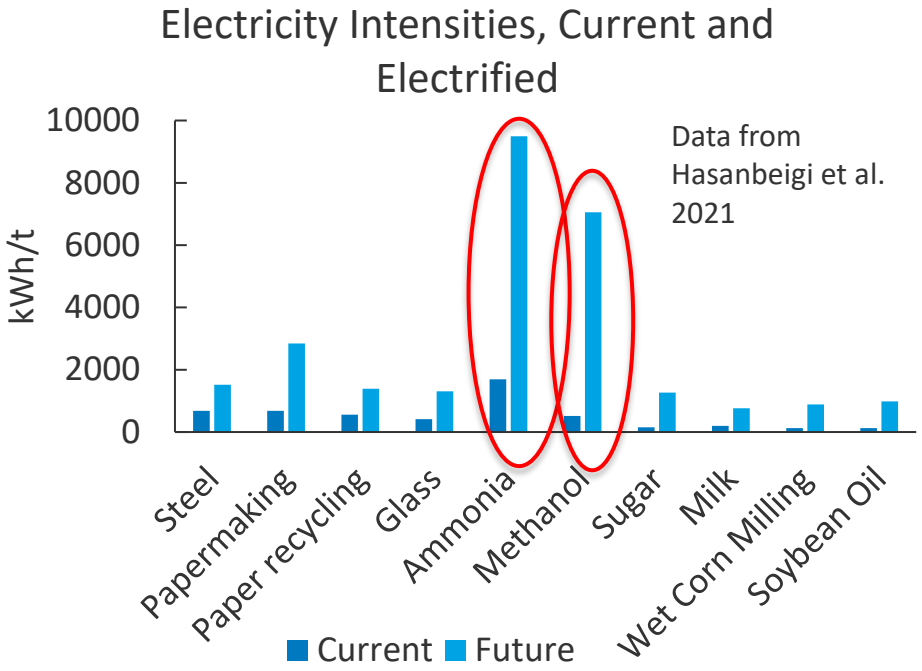


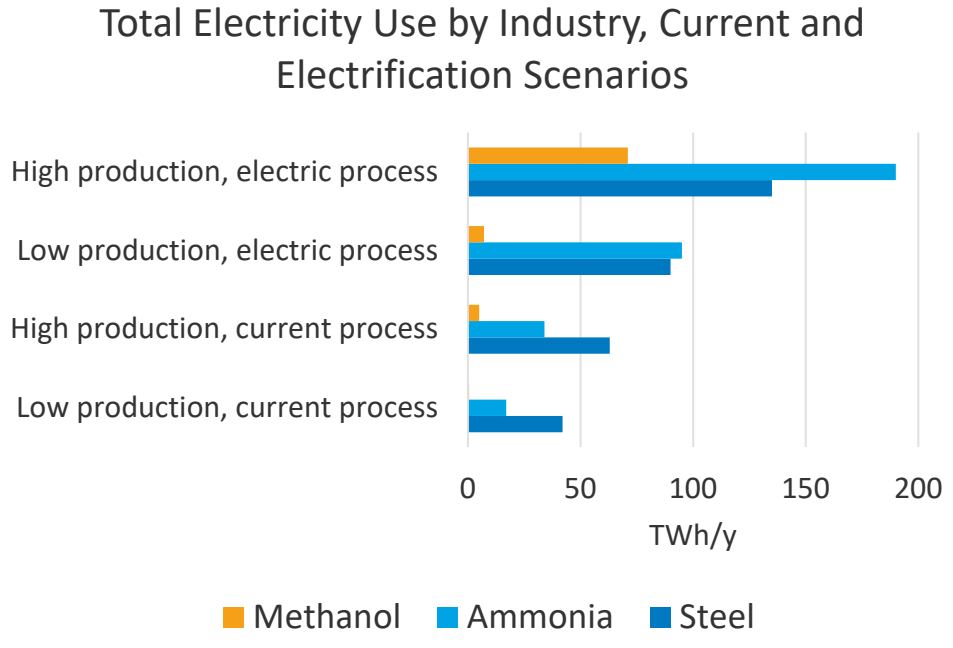
Murphy et al. 2021. Electrification Futures Study: Scenarios of Power System Evolution and Infrastructure Development for the United States.

US >1,200 GW capacity Feb 2022

Electrification of Manufacturing

Electrification pathways increase industrial electricity demand & change use patterns

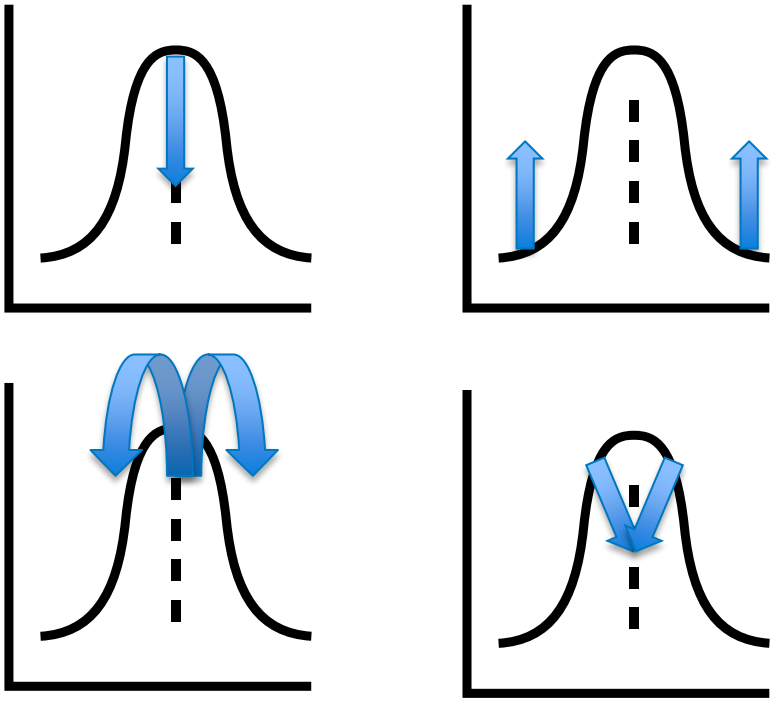




Ammonia production based on electrolytic hydrogen could overtake steel as largest manufacturing electricity user at current capacity levels

What is Demand-Side Load Flexibility?

System



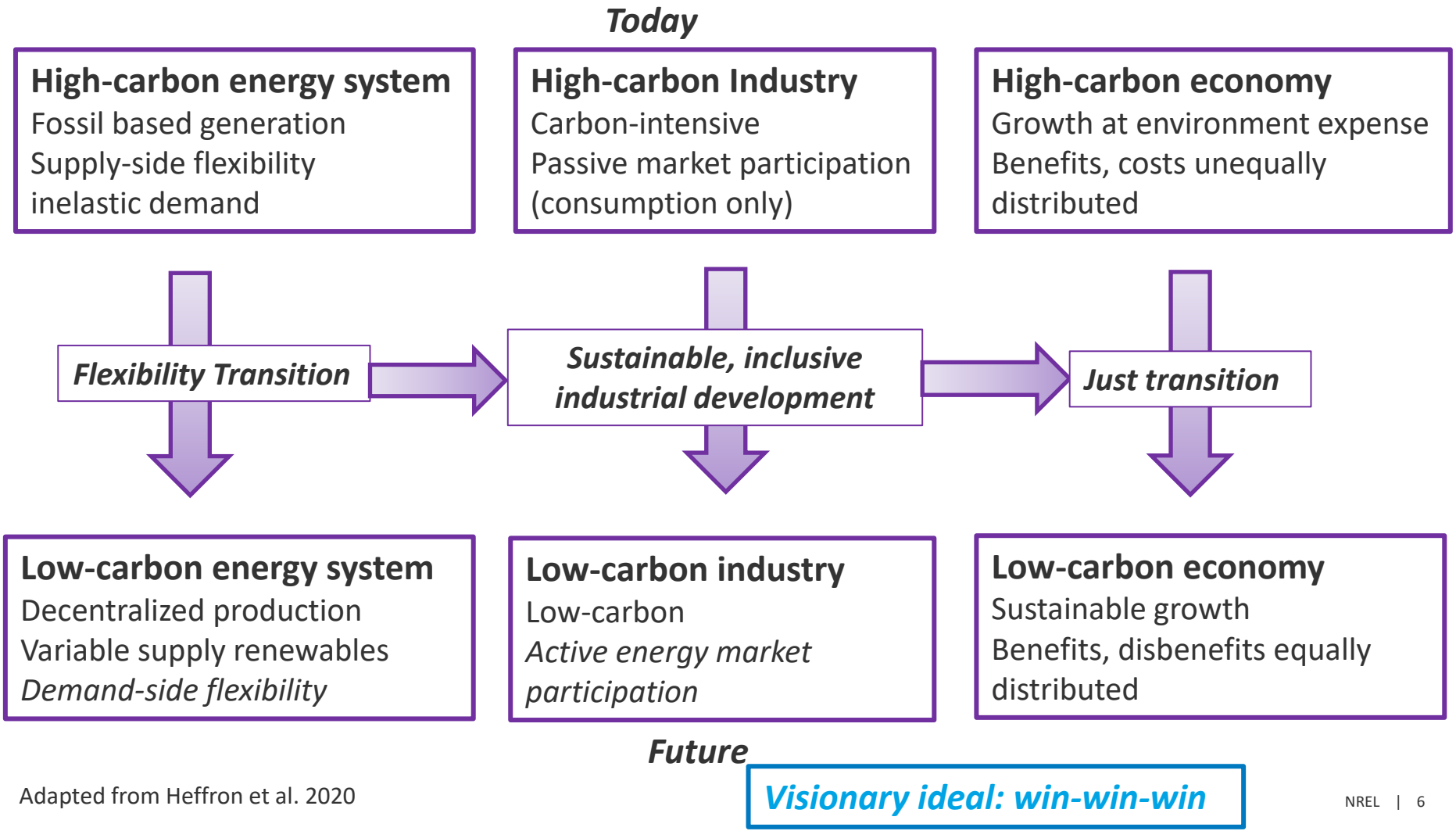
Operations

- Energy storage systems
- Co-generation/hybrid systems
- Load shedding
- Load shifting
- Energy efficiency
- Waste heat recovery

Commodification

- Interruptible rates
- Direct load control
- Time of Use/Real-time Rates
- Ancillary services markets
- Arbitrage

Low-cost, efficient, fast, provided by industry



Adapted from Heffron et al. 2020

Framework: Technological Innovation Systems

Dimension	Category
Actors	• Companies, institutes of learning, government, NGOs, other stakeholders
Institutions	• Hard: laws and regulations • Soft: Customs, norms, routines
Interactions	• Networks • Between individuals
Infrastructure	• Physical • Knowledge • Financial

Functions
F1: Entrepreneurship
F2: Knowledge development
F3: Knowledge diffusion
F4: Guidance of the search
F5: Market formation
F6: Resources Available
F7: Creation of legitimacy
F8: Positive Externalities

(Hekkert et al. 2007; Bergek et al. 2008; Markard and Truffer 2008)

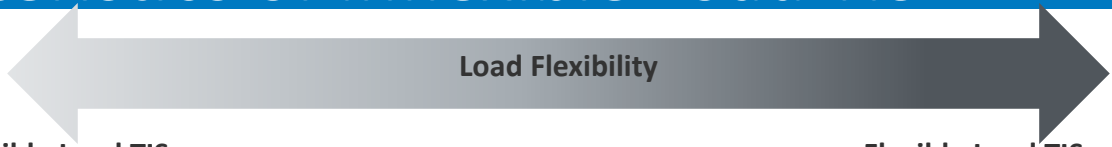
A structural-functional approach to detect barriers and opportunities for innovation

Interviews

- 20 interviews with 22 stakeholders
  - Semi-structured
- 4 categories: markets, industry, steel, green ammonia
- Grid operators, industry associations, universities, regulatory, consulting, start-ups, utilities
- Engineers, managers, professors, consultants, economists, vice presidents, directors, presidents, researchers, CEOs

Conversations with stakeholders throughout value chain

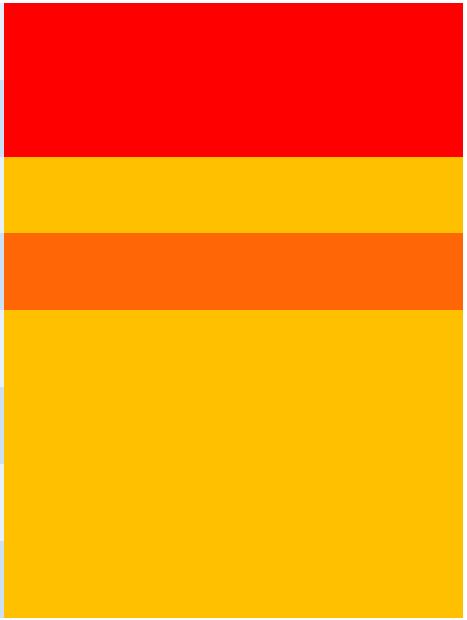
Characteristics of Inflexible Load TIS



Actors: Chemical companies, refineries
Interactions: Failure to find compensation agreement
Institutions Hard: EHS, demand charges; fixed rates; DR opt-out Soft: continuous operation, standard operating procedures, focus on yield maximization, stakeholder opposition to 'double payment', lack of knowledge/instruction on dynamic operations
Infrastructure Physical: Process health and safety issues if interrupted; thermal chemical process; lack of smart sensors, meters, storage Knowledge: Highly optimized continuous/steady; ISO infrastructure Financial: Large capex, low specific electricity consumption

industry and market dimensions can both complicate industrial flexibility

TIS - Market

F1: Entrepreneurship	
F2: Knowledge development	
F3: Knowledge diffusion	
F4: Guidance of the search	
F5: Market formation	
F6: Resources Available	
F7: Creation of legitimacy, organization	
F8: Development of Positive Externalities	

Hurdles: Lack of profit, not focus of R&D, market operators agnostic to resource type, operational difficulties and resistance

TIS – Flexible Green Ammonia

F1: Entrepreneurship	
F2: Knowledge development	
F3: Knowledge diffusion	
F4: Guidance of the search	
F5: Market formation	
F6: Resources Available	
F7: Creation of legitimacy, organization	
F8: Development of Positive Externalities	

Strong interest and movement here not yet aided by regulations, certifications; flexibility link with VRE, not always with power grid

Trends

Markets	Green Ammonia
• Stable/declining industry DR participation *except* cryptocurrency, data centers. • longer downtimes when called • more calls to emergency resources	• Significant increase in interest • Interest from utilities • Speaking invitations, attendance • Funding, conversations

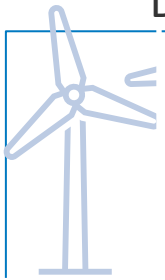
‘We do have people on curtailable rates, the contract says if the grid is getting overloaded we've got to shut you down, that actually happened last year and they were very angry about it. It's not like a sophisticated operation, based on the day ahead, they'll call you up’ –Interviewee 19, Markets

NREL Image

Stable industrial DR; momentum building in green ammonia sector

Decarbonization Pathways for Ammonia

Distributed green ammonia



New producers

New locations

Limited grid connection

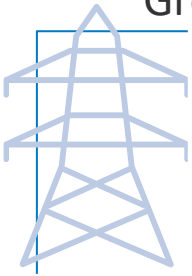
Blue ammonia

Existing producers

Existing locations and similar infrastructure

Demand response possible

Green ammonia for power plants



Existing producers?

Existing locations and similar infrastructure?

Retrofit of existing power plants

Peaking plants running on green fuels

Green ammonia from purchased H_2

Large-scale, centralized production… by whom?

Locations close to hydrogen hubs

Grid flexibility from hydrogen hubs rather than ammonia

Producers/actors

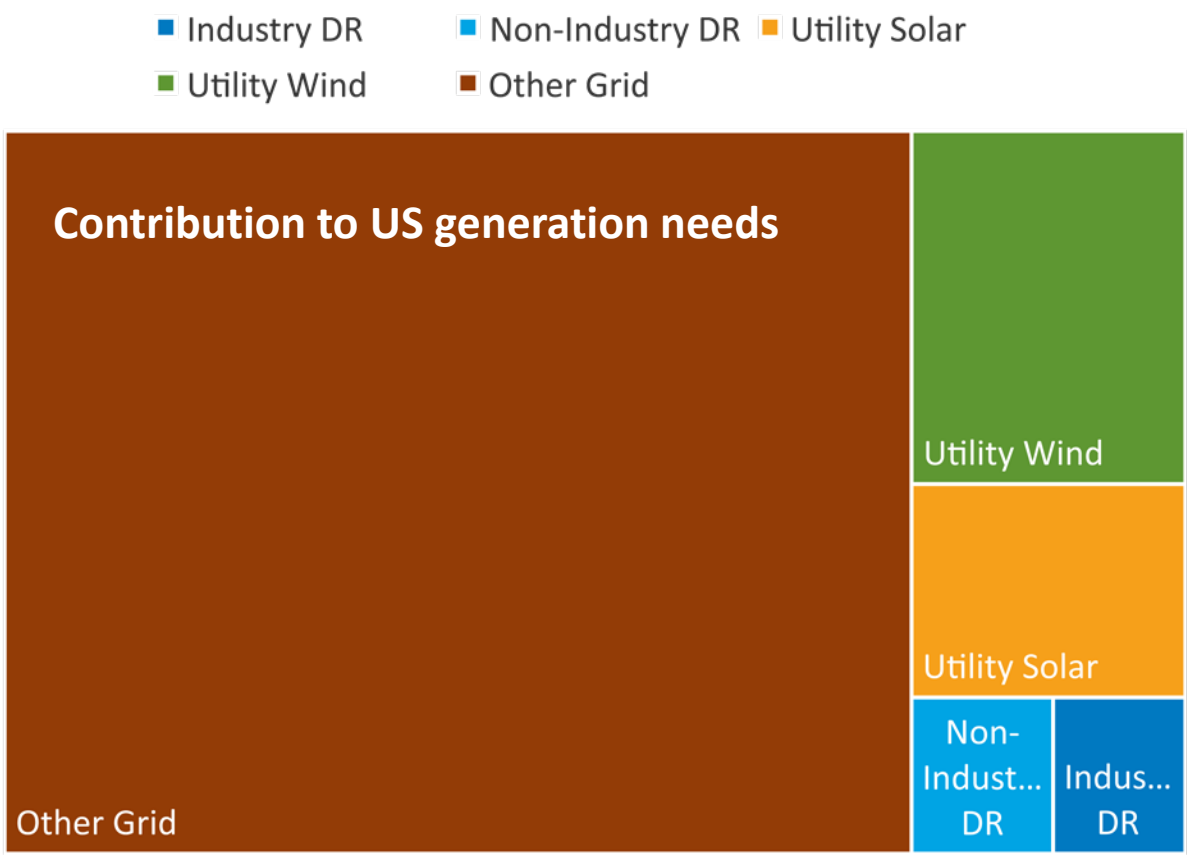
Infrastructure/location

Flexibility

Different pathways have diverse flexibility outcomes; might not add to grid load, flexibility need

Flexibility Transition - Conclusions

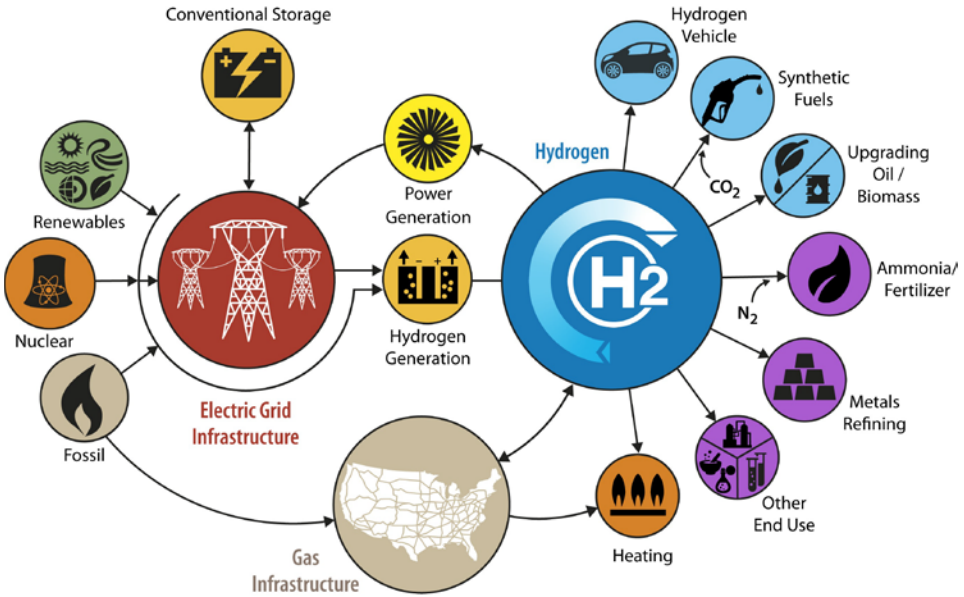
- US flexibility transition not just beginning…
- Most via interruptible programs
  - Not flexibility justice/2-sided market
- Regulatory frameworks do not target industry
  - Agnostic resource type
  - ***No one's focus***
- ***Transition motivated by sustainability***
  - ***But no direct linkage between flexibility/ghg***



We did not find a TIS functioning around flexible industrial loads

Green Ammonia - Conclusions

- Electrolytic H_2 to ammonia – 'power to X'
  - Large scale production challenging
    - Smaller scale production is new paradigm…
      - for flexibility, practices, infrastructure, institutions
      - grid connection?
    - Grid factor for CO_2 must be low
  - Integration to the grid → demand for capacity, flexibility in DR
  - Changing production locations
  - Changing producers



Different practices and paradigms for flexibility

Graphic by Al Hicks / NREL

TIS - Conclusions

No TIS functioning around flexible industry loads

Context important

- Clarity lacking on designs
- Tapestry of regulations – context-specific strategies
- Communication necessary

Flexibility commodification now based on $ alone

- Higher flexibility need/transition tied to ESG
- No explicit tie to resource mixture
- Cannot help facilities meet scope 2 emissions goals

Electrification and power-to-X change practices

- New paradigms for flexibility

Thank You

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NREL/PR-6A20-84469

Special acknowledgment to all of the interviewees who shared their time and expertise with us.