Industrial load flexibility, the US power grid and ammonia

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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?


US >1,200 GW capacity Feb 2022
**Electrification of Manufacturing**

*Electrification pathways increase industrial electricity demand & change use patterns*

**Electricity Intensities, Current and Electrified**

Data from Hasanbeigi et al. 2021

**Total Electricity Use by Industry, Current and Electrification Scenarios**

- High production, electric process
- Low production, electric process
- High production, current process
- Low production, current process

**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
High-carbon energy system
- Fossil based generation
- Supply-side flexibility
- Inelastic demand

High-carbon Industry
- Carbon-intensive
- Passive market participation
  (consumption only)

High-carbon economy
- Growth at environment expense
- Benefits, costs unequally distributed

Flexibility Transition

Sustainable, inclusive industrial development

Just transition

Low-carbon energy system
- Decentralized production
- Variable supply renewables
  
  Demand-side flexibility

Low-carbon industry
- Low-carbon
- Active energy market participation

Low-carbon economy
- Sustainable growth
- Benefits, disbenefits equally distributed

Today

Adapted from Heffron et al. 2020

Future

Visionary ideal: win-win-win
Framework: Technological Innovation Systems

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Category</th>
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<tbody>
<tr>
<td>Actors</td>
<td>- Companies, institutes of learning, government, NGOs, other stakeholders</td>
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<tr>
<td>Institutions</td>
<td>- Hard: laws and regulations</td>
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<td>- Soft: Customs, norms, routines</td>
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<tr>
<td>Interactions</td>
<td>- Networks</td>
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<td></td>
<td>- Between individuals</td>
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<tr>
<td>Infrastructure</td>
<td>- Physical</td>
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<td></td>
<td>- Knowledge</td>
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<td>- Financial</td>
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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

**Agractors:** 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

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*industry and market dimensions can both complicate industrial flexibility*
TIS - Market

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**Hurdles:**
- Lack of profit, not focus of R&D, market operators agnostic to resource type, operational difficulties and resistance
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*Strong interest and movement here not yet aided by regulations, certifications; flexibility link with VRE, not always with power grid*
### Trends

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<td>• Stable/declining industry DR participation <em>except</em> cryptocurrency, data centers.</td>
<td>• Significant increase in interest</td>
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<td>• longer downtimes when called</td>
<td>• Interest from utilities</td>
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<td>• more calls to emergency resources</td>
<td>• Speaking invitations, attendance</td>
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<td>• Funding, conversations</td>
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‘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

**Stable industrial DR; momentum building in green ammonia sector**
Decarbonization Pathways for Ammonia

**Distributed green ammonia**
- New producers
- New locations
- Limited grid connection

**Green ammonia for power plants**
- Existing producers?
- Existing locations and similar infrastructure?
- Retrofit of existing power plants
- Peaking plants running on green fuels

**Blue ammonia**
- Existing producers
- Existing locations and similar infrastructure
- Demand response possible

**Green ammonia from purchased H₂**
- 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 H₂ 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 CO₂ 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
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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