Tutorial Overview

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ESIG Spring Workshop Tutorial

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

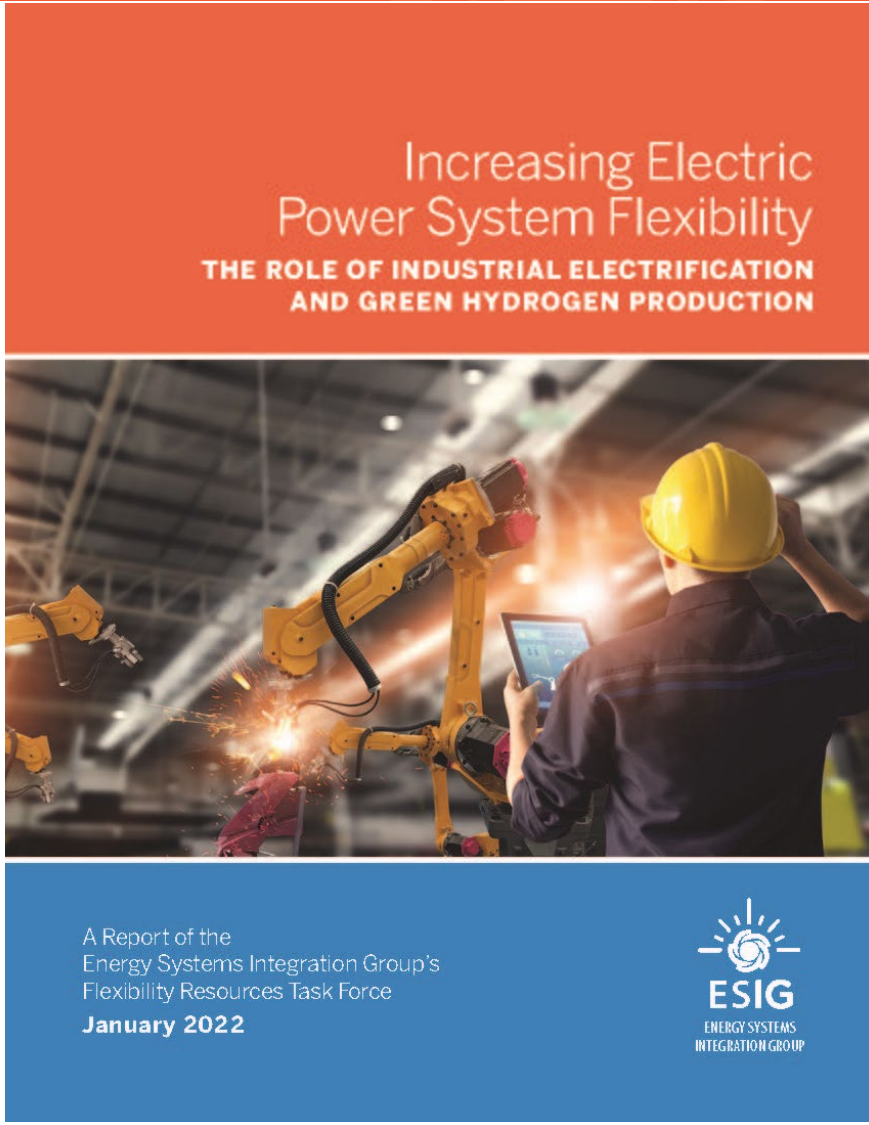
March 21, 2022

Agenda

- Introduction and Review of Recent Paper - A. Tuohy(15 min)
- Introduction to Hydrogen – W. D'haeseleer
- Q&A
- *30 minute break*
- Panel Discussion
  - Brittany Westlake, EPRI
  - Pierluigi Mancarella, University of Melbourne
  - Elizabeth Endler, Shell
- Q&A/Discussion

Recent Report Release – Available Now!

- Available at esig.energy (link)
- Lead Authors:
  - Aidan Tuohy, Electric Power Research Institute
  - Niall Mac Dowell, Imperial College London
- Task Force Members
  - Julian Beere, Anglo American
  - William D’haeseleer, KU Leuven
  - Elizabeth Endler, Shell
  - Anthony Ku, NICE America Research
  - Pierluigi Mancarella, University of Melbourne
  - Julia Matevosyan, Energy Systems Integration Group
  - Toby Price, Australian Electricity Market Operator
  - Ehsan Shafiei, Concawe
  - Marta Yugo, Concawe



Background/Objective of Task Force Report

- Increasing deployment of renewable resources around the world envisioned to decarbonize power systems
  - Reducing availability of traditional sources of flexibility while increasing value of flexibility
  - Increased electrification of energy system to take advantage of clean renewables

- Newly electrified resources have the potential to provide significant flexibility
  - Examined from the context of 70%+ renewable energy, where flexibility is increasingly important
  - Oversupply conditions may result in abundant low cost renewables available
  - Deficits in energy requires long duration storage, clean firm power or some other means of ensuring resilience

- The report discusses the electric power systems perspective for these new electrical loads

Focus is more on how we will plan and operate power systems where hydrogen and industrial electrification are major contributors of flexibility, less on the pathways to decarbonize

Industrial Electrification

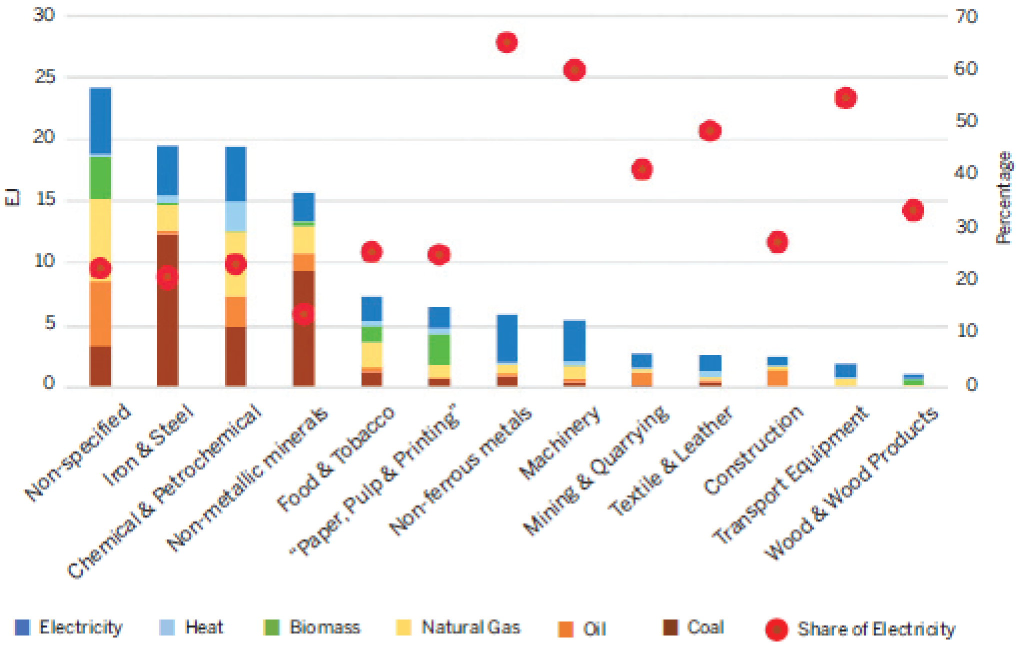
- Wide range in how electricity is used in Energy Intensive Industries (EIIs) today – 14% (e.g., ceramics) to 65% (aluminum)
  - Some EEIs have clear path – others require technology development (e.g., lower temp can be quickly transitioned, but more work for >1000°C (e.g., cement/glass)
  - Process electrification, e.g., use of secondary steel produced in electric arc furnaces, is an area of focus
  - Other processes may need greater technology development into 2030s, and link to hydrogen

- Flexibility as a demand resource – direct control or price-based
  - Possible for some processes such as smelting to provide flexibility to shift some demand
  - Grid services are also possible from EEIs
  - Greater share of EEI coming from electricity will result in significant increase in electicity demand (e.g., EU shows 4x)

- Barriers like those associated with efficiency (equipment costs, policy) but with additional of technology development needed in some areas
  - Also need to determine economics if providing flexibility
  - Potential competitive disadvantage if not well designed

FIGURE 1

Source of Energy and the Proportion of Total Energy Demand Represented by Electricity, by Industry



The energy demand for each industry is on the left axis and represented by the colored bars, which indicate the source of energy used in those industries in exajoules (EJ). (One exajoule is 10^{18} joules, or 277.77 terawatt-hours (TWh)). Note that this is the amount of final energy consumption from each source and not electrical energy.) The share of total energy demand that is provided by electricity is on the right axis, represented by the red dots. Each dot shows the current use of electricity as a percentage of total energy; for example, for chemical industries, electrical energy provides approximately 20 percent of total energy use, whereas for machinery it provides a little more than 60 percent.

Source: Wei, McMillan, and de la Rue du Can (2019).

Hydrogen

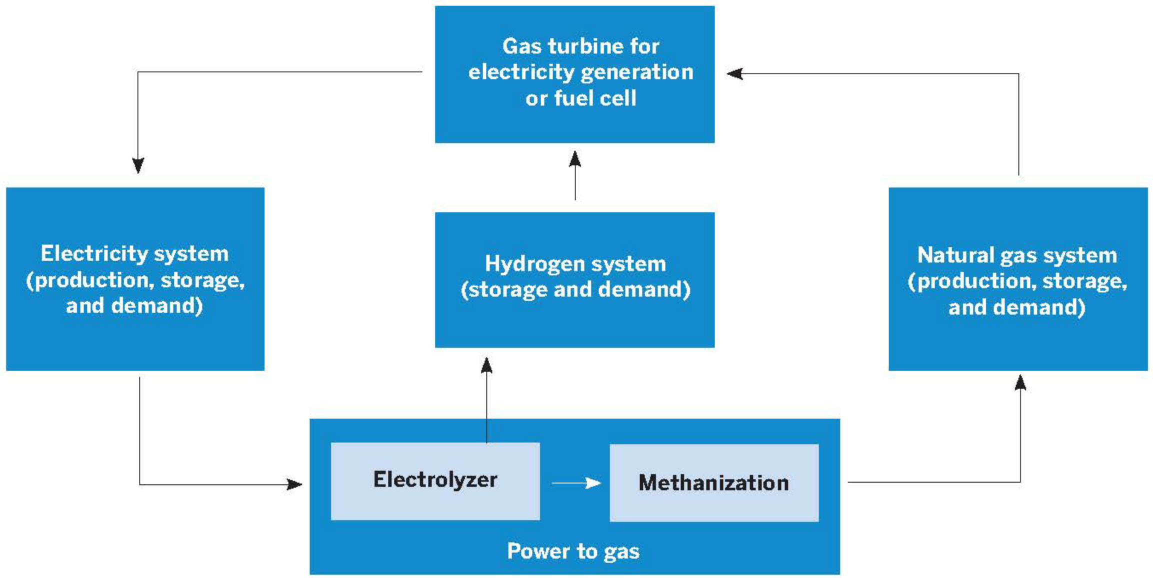
- Hydrogen has been identified as having a potentially major role in decarbonization
  - Often seen as the last piece (or a later piece) in the puzzle for clean energy systems

- Report considers where it may play a role and answers questions such as
  - Is it primarily likely to be load or as a round trip provider of electricity also (fuel cells, methanization)?
  - What technology development is required?
  - What are the costs considerations?
  - How will it fit into grid operations and planning?

- Use as a flexible load is likely to be the main use in coming years, and maybe always
  - Demand side role is more suitable given costs and technology, at least for 15-20 years before it becomes a major producer of electricity (and that depends on what other options are available)
  - Two-way production is discussed also for what is needed for it to happen

Power to Gas System

The Main Elements of a Power-to-Gas System



Notes: The colors have no relationship to the conventional colors typically assigned to hydrogen. This figure is simplified to provide general context and as such misses some more detailed aspects of the system, including CO_2 streams to and from the gas system and steam methane reformers, and other technologies that are likely to accompany these systems such as carbon capture, utilization, and storage and direct air capture. While important in the overall context, they are less relevant to the interactions between green hydrogen, the electric power system, and the gas system that is the focus of this report. See Belderbos (2019) for a more detailed example of the full interactions.

Source: Energy Systems Integration Group.

Power to gas is one potential means to produce hydrogen and use it for other applications

- Could go to industrial processes with some storage needed also
- Could be methanized and injected into the natural gas network

Some portion of this may be used to produce electricity through gas turbines or fuel cells

- Typically very small amount of total energy envisioned (e.g., 5% of global energy in IEA study)
- But this could be an important energy resource for periods of low wind/solar

Costs of two-way coupling could be very challenging – lower reductions for fuel cells

Hydrogen can also be more valuable in other systems that are harder to decarbonize than electricity

Flexibility from hydrogen

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- Initially expected as a source of demand side
  - Production of hydrogen through electrolyzers with clean electricity
  - Use in other industries as a feedstock to decarbonize there
  - Pockets may develop with unidirectional flexibility to make use of renewables and then be used from system side at other times
- Fuels can be produced away from where they are needed and transported
  - Requires consistent accounting of carbon costs/emissions
  - Could produce in places with high wind/solar potential (e.g. MENA, Australia, etc.)
  - Imported into places with less resources but suitable H_2 networks
    - US – currently has 1, 600 miles of hydrogen pipelines, 320,000 circuit miles of gas transmission
  - Will also impact markets – price formation, energy, capacity, etc.

ENTSO-E has formulated recommendations for policymakers on:

› **The new roles of hydrogen**
Hydrogen is a tool for reaching decarbonisation targets and not an end in itself

› **Where we are now and the next steps towards bigger hydrogen**
The business case to use hydrogen in an electricity system operation support function does not currently exist

› **Planning and operating hydrogen in 'one system of systems'**
A unified system perspective (one system view) is necessary

ENTSO-E, Nov 2021 (link)

Green hydrogen now cheaper than blue in Middle East, but still way more expensive in Europe

RECHARGE
Global news and intelligence for the Energy Transition

Hydrogen Characteristics and Grid Services

Range of different technologies available with different potential characteristics for power system

Electrolyzers may be quick responding and could provide grid services

Will also need to have storage and/or connection to a hydrogen grid

Some technologies may be reversible

Gas turbines may be fitted to be powered by hydrogen

Technical and Economic Parameters for Different Types of Electrolyzers under Development

	Alkaline Electrolyzer			PEM Electrolyzer			SOEC Electrolyzer		
	Today	2030	Long Term	Today	2030	Long Term	Today	2030	Long Term
Electrical efficiency (%, LHV)	63–70	65–71	70–80	56–60	63–68	67–74	74–81	77–84	77–90
Operating pressure (bar)	1–30			30–80			1		
Operating temperature (°C)	60–80			50–80			650–1,000		
Stack lifetime (operating hours)	60,000–90,000	90,000–100,000	100,000–150,000	30,000–90,000	60,000–90,000	100,00–150,000	10,000–30,000	40,000–60,000	75,000–100,000
Load range (%, relative to nominal load)	10–110			0–160			20–100		
Plant footprint (m^2/kW_e)	0.095			0.048					
CAPEX (USD/kW_e)	500–1,400	400–850	200–700	1,100–1,800	650–1,500	200–900	2,800–5,600	800–2,800	500–1,000

Note: LHV = lower heating value; m^2/kW_e = square meter per kilowatt electrical. No projections made for future operating pressure and temperature or load range characteristics. For SOEC, electrical efficiency does not include the energy for steam generation. CAPEX represents system costs, including power electronics, gas conditioning, and balance of plant. CAPEX ranges reflect different system sizes and uncertainties in future estimates.

Source: International Energy Agency (2019), The Future of Hydrogen: Seizing Today's Opportunities. All rights reserved.

System Operations and Planning Needs

- EIIs and hydrogen production need to be more deeply integrated into planning processes
- Additional work is needed to understand the implications of new sources of flexibility for electricity system operations and market operations
- Improved performance and lower costs in industrial electric technologies are needed, especially for high-temperature processes
- Pilots and demonstrations carried out to assess the use of hydrogen as a resource

New Task Force Focused on Next Steps

- Focus is on how to integrate hydrogen and EEIs into planning processes and identify changes needed to operations
- Idea of breaking down the various planning processes
  - What do we know now about these new technologies and how they fit?
  - What gaps do we have
    - Transmission/network modeling
    - Resource planning
    - Operational models
    - Market models
  - What testing/demonstration needs to be done
  - What technology developments are needed from power system perspective?
- Desktop exercise focus – not detailed modeling but may be able to conceptually walk through how to plan for these resources and identify what is missing/what is known

- Will discuss scope during Thursday's WG meeting (System Operations and Market Design)
- Looking for volunteers to participate in the task force – plan to have report in ~6 months
- Meeting 6-8 times over TF, and potentially contributing to writing/modeling
- Please contact atuohy@epri.com if you would like to participate!

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THANK YOU

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