The Road to Clean Hydrogen: Getting the Rules Right

July 2023

The “three pillars” being considered for implementation could potentially impact the rate at which PTC ramps-up the green hydrogen economy

PTC pillars	Definition	Implication (based on analysis by Plug)
Additionality	Green hydrogen to be produced using **newly-built clean energy assets** constructed primarily for this purpose	• **Makes renewable power a value chain control point and limits business models** • **Reduces the benefits of green hydrogen** • **Delays green hydrogen projects by 5+ years** • **Prevents ~200,000 jobs from being created and reduce carbon abatement by ~50%**
Hourly time-matching	Clean power used for electrolyzer operation to be **produced in the same hour it was consumed**	• **Increases green hydrogen production costs by ~\$1.3/kg (~50% of PTC)** • **Not yet widely available** creating delays of several years in green hydrogen projects • **Reduces green hydrogen investments of ~65% by 2032, ~90% of gross jobs through 2035, green hydrogen demand of ~75% in 2040, and emissions by ~540Mn tCO2eq of GHG and ~4.2 micrograms/m3 PM2.5 by 2040**
Strict local geographic matching	Green hydrogen production to be at **minimum geographic proximity and grid connectivity** from the source of clean power (e.g., direct connection)	• **Increases green hydrogen production costs by ~\$1/kg (~35% of PTC)** • **Creates regional winners and losers** • **Counterproductive to other federal programs (i.e., DOE Hydrogen Hubs)** • **Inflates hydrogen logistics and distribution costs**

Implementing both strict local matching and 100% hourly time-matching **in 2025 could increase Levelized Cost of Hydrogen (LCOH) to the extent that green hydrogen producers would opt out of the PTC.**

Additionality, Time Matching, and Regionality are not included in the legislative language, any legislative intent or colloquies associated with 45V PTC.

The intent of the PTC in the Inflation Reduction Act (IRA) is to rapidly scale clean hydrogen production, not overly regulate it. **The three pillars are not within the legislative intent.**

Source: Inflation Reduction Act, Plug analysis

Overview of context and objectives for this study

Context

- The Clean Hydrogen Production Tax Credit (PTC) in the Inflation Reduction Act (IRA) is likely to be one of the largest drivers for decarbonization, job creation, and US clean tech competitiveness in the next decade
- In the next several months, the implementation guidance for the PTC are being finalized; one primary uncertainty is around the "three pillars" for clean power time-matching, additionality, and regionality/ proximity to the electrolysis source (e.g., same balancing zone)

Objectives

Test out the potential implementation of the PTC under the "three pillars" and their impacts on gross[1] socioeconomic and decarbonization factors, we run the study detailed herein with the following objectives:

- **Develop scenarios for implementation of the hydrogen PTC** with a focus on additionality, time-matching, and regionality
- **Understand the implications** on levelized cost of hydrogen (for 2025 and 2030), for a variety of project archetypes
- **Estimate the deployment implications** for green hydrogen economy in the US for each of the scenarios
- **Determine the gross impacts on the following metrics:**
  - Gross investment impact, i.e., investments into green hydrogen production – there are investments in upstream and downstream steps of the value chain (e.g., renewables); those are not quantified
  - Gross job implications (direct and indirect)
  - Gross societal emissions impacts (GHG and particulate matter)

Plug was responsible for the analysis of the legislation and development of the scenarios

1. *Gross impact considers the impact on the green hydrogen economy only, without considering other clean technologies that could potentially replace green hydrogen to back-fill decarbonization needs.*

Analyses leverage public market data, and Plug's industry knowledge and previous studies

Industry reports and data

Market report sources

- U.S. National Hydrogen Strategy & Roadmap
- Department of Energy's (DOE) Pathways to Commercial Liftoff report
- Hydrogen Council Global Hydrogen Flow report
- Long Duration Energy Storage (LDES) Council – A path towards full grid decarbonization with 24/7 clean power purchase agreements

Public data review

- Argonne National Laboratory Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model for fuel carbon intensity
- California Air Resources Board's Low Carbon Fuel Standard (LCFS) Fuel Pathways for fuel carbon intensity
- US Environmental Protection Agency Compilation of Air Emissions Factors
- LevelTen data on Power Purchase Agreement (PPA) prices
- Energy Acuity data on Renewable Energy Credit (REC) prices
- U.S. Energy Information Administration (EIA data) on grid prices for industrial consumers
- National Renewable Energy Laboratory (NREL) solar and wind capital cost
- Lawrence Berkeley National Laboratory analysis on interconnection queues
- Air Products public announcements on new facility costs

Plug industry knowledge

- Plug Power's near term clean hydrogen deployment projects
- Plug Power's Socioeconomic Impact of hydrogen effort, May 2022
- Hydrogen jobs model

Additionality impacts go beyond project-level economics

1

Delays the green hydrogen value chain development

At least **5 years of delays** in the interconnection queues for new RES capacity would translate into **delays for green hydrogen projects**

2

Poses difficulties in tracking what is truly additional

It could be **challenging to identify resources that would not otherwise have been present** without the demand for green hydrogen

3

Makes renewable power a value chain control point

Limiting the available supply of qualifying RES projects could create a supply shortage and **increase power costs on green hydrogen developers**

4

Limits business models that reduce decarb. cost

Leveraging financially distressed RES projects would not be possible with additionality, **limiting potential system cost savings**

5

Reduces system benefits of green hydrogen as a source of power flexibility

Green hydrogen provides system flexibility by taking renewables that would have been otherwise curtailed or when low/negative power prices exist; hence potentially **reducing overall system costs and improving grid reliability and performance.**

Other considerations

New RES could be driven by market forces regardless

With new demand and incentives at the state and federal (i.e., IRA) level for solar and wind generation, **significant new capacity is expected to come to the market regardless** of additionality

Required energy capacity is small compared to RES pipeline

1,300GW of solar and wind capacity is currently seeking connection to the grid, vs ~30GW electrolyzer deployment by 2030, **which amounts to <3% of potential capacity RES capacity**

Many policies driving new clean energy demand do not require additionality

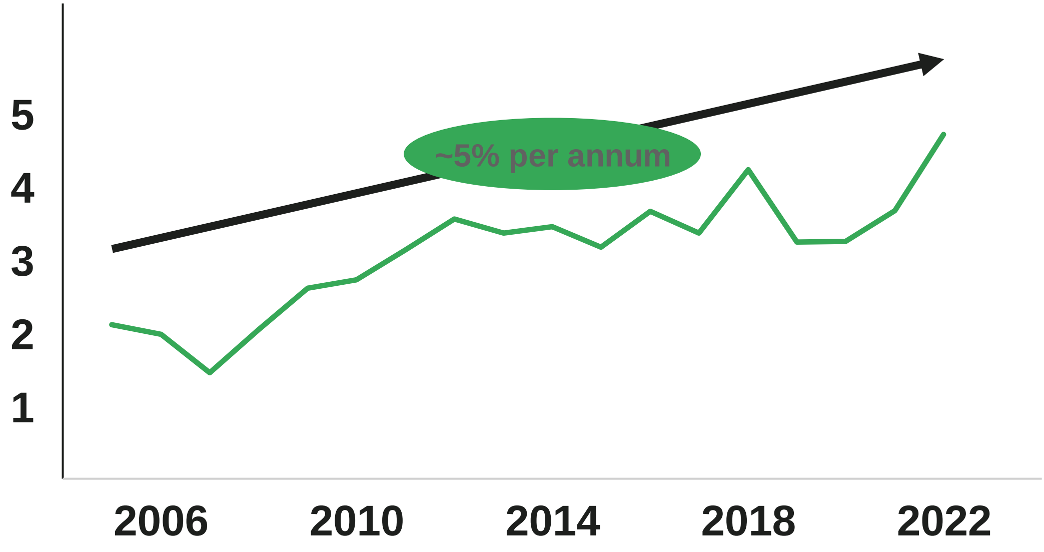
For example, EPA EO 14057 requires 100% renewable power by 2030, with 50% hourly time matching for Federal Government electricity demand, **without requiring clean energy to be additional**

Source: Plug Power analysis

Renewable projects today face 5+ year waiting times in the interconnection queue, which would push out green hydrogen scale up and supply

The increase in number of interconnection requests has caused increasing wait times for new capacity to be interconnected to the grid; projects interconnected in 2022 took on average **5+ years to progress from interconnection request to commercial operations**[1]

Interconnection queue, *years to get interconnected*



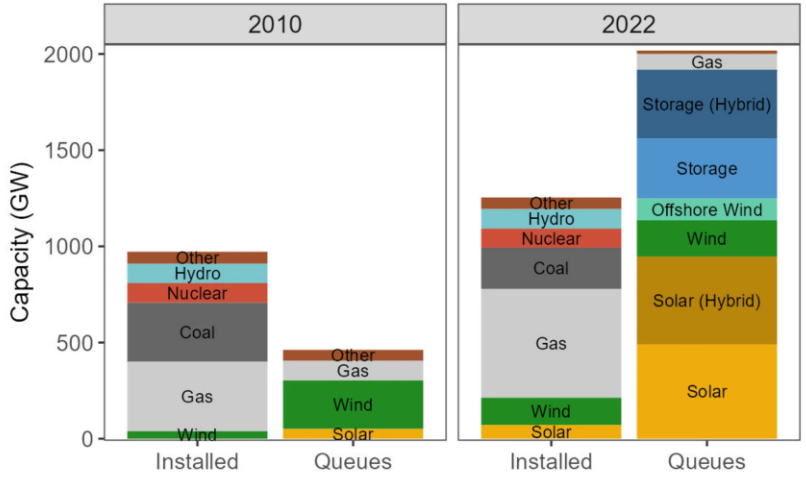


Image courtesy of Joseph Rand at Lawrence Berkeley National Laboratory

- An additionality requirement would **directly tie clean hydrogen production to the interconnection challenges of the electric grid.**
  - This would **impose the current delays (5+ years)** and timelines for renewable development upon the hydrogen economy as well.
- There is **significant renewable resources already in the queue** with the rate of deployment expected to increase significantly with the IRA.
  - Projections for hydrogen deployment over the rest of the decade indicate a maximum of 30 GWs of electrolyzers deployed by 2030.
  - **Clean hydrogen would represent <1% of the renewable supply projected to be available in 2030.**

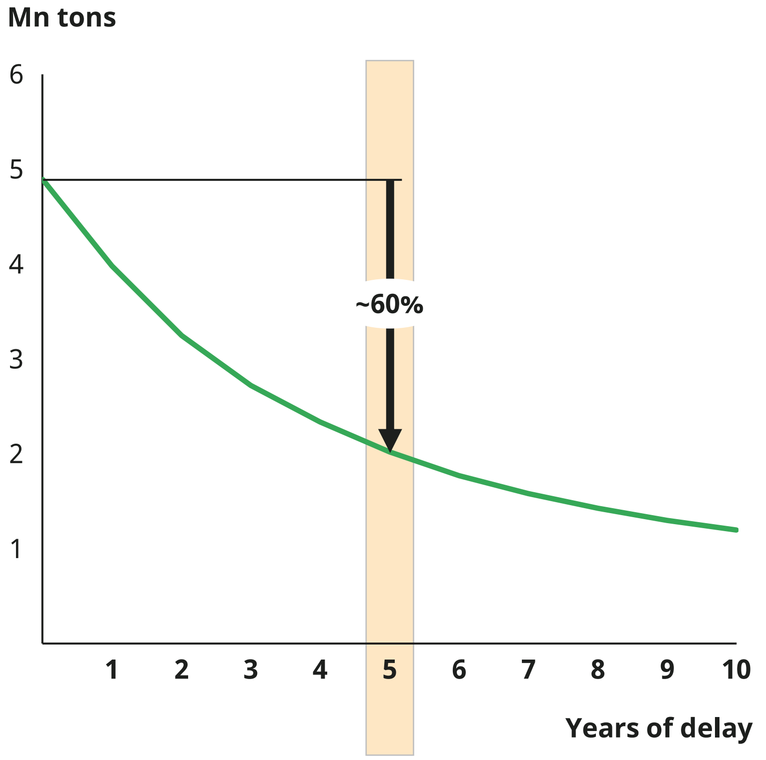
1. Includes only 58% of all operational projects due to the availability of in-service date.

Source: Lawrence Berkeley National Laboratory, Plug Power analysis

Delay in scale up would prevent ~250,000 jobs from being created and reduce carbon abatement by ~50%

Expected delay in COD based on current interconnection queues

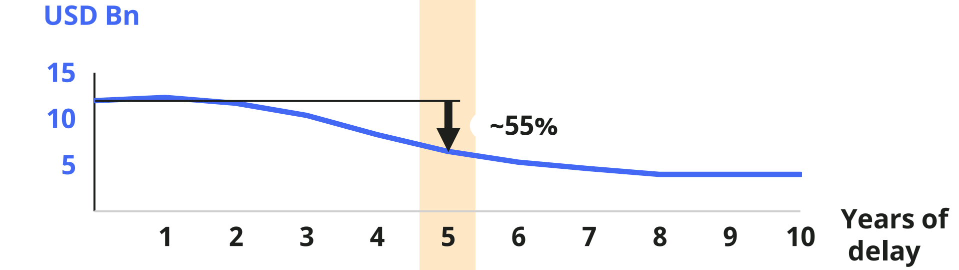
Gross green hydrogen demand[1] in 2030:



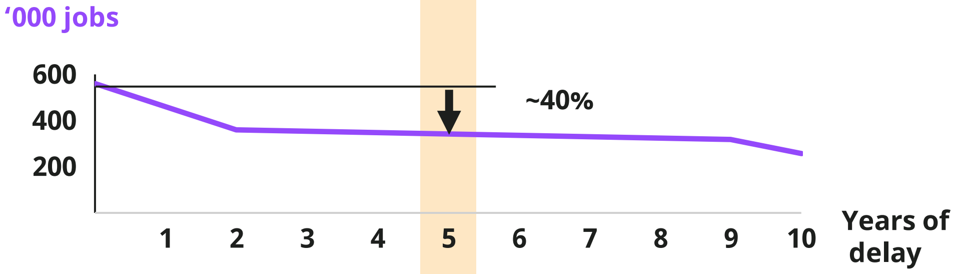
Gross[2] impact on investments, GHG abatement, and PM2.5 concentration

Considering additionality requirement only (excl. impact of local geographic matching and hourly time-matching)

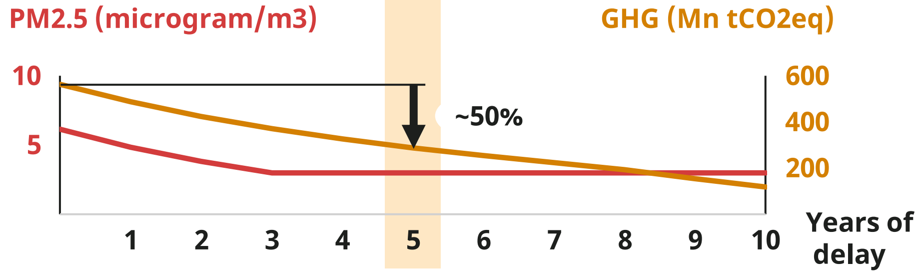
Gross investment in 2030: based on current interconnection queues, additionality could delay required investment volume to ~55% of baseline volume



Gross jobs[3] in 2030: gross job volume would likely drop by ~40%, if additionality causes delay in direct and indirect employment associated with hydrogen production



Gross environmental impact in 2030: both PM2.5 and GHG abatement potential could drop by ~50% by 2030, with PM2.5 abatement projected to drop faster due to the high sensitivity of transportation demand to delays



1. Petroleum refining is excluded to eliminate confounding effect of demand increase.
2. Gross impact considers the impact on the green hydrogen economy only, without considering other clean energies that could potentially replace green hydrogen to back-fill decarbonization needs.
3. Only direct and indirect jobs are considered.

Source: Lawrence Berkeley National Laboratory, Plug Power analysis

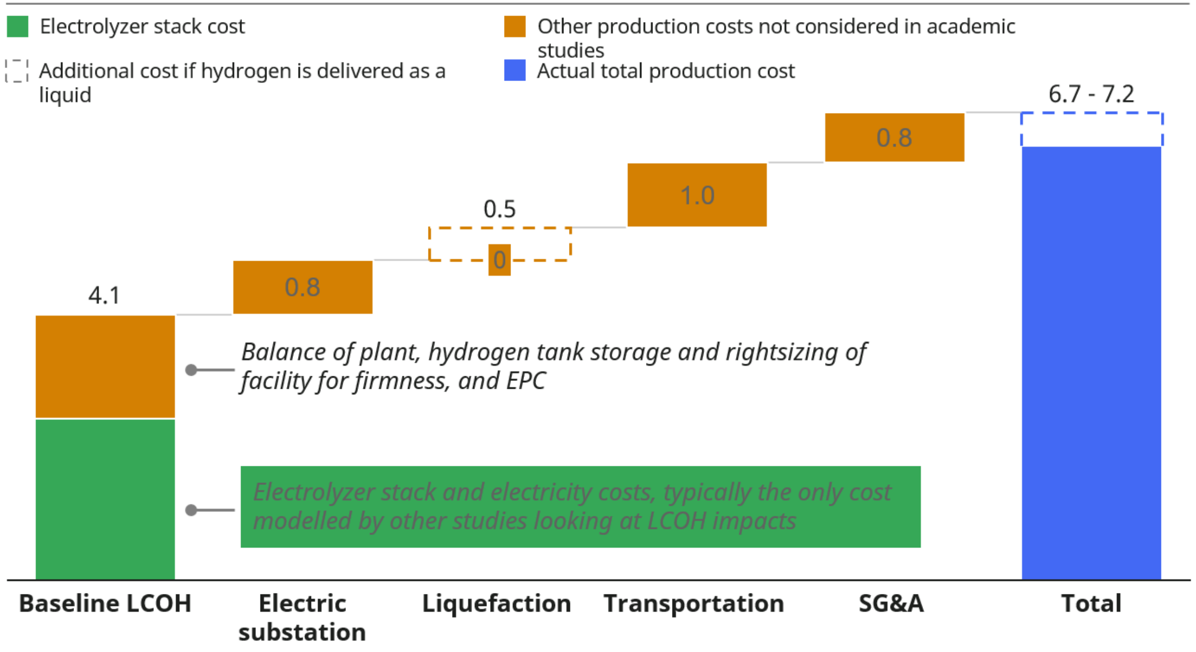
Other analyses cite lower impacts of the three pillars on LCOH; this seems to be driven by 4 key differences in underlying assumptions

1	**No hydrogen production plant operational requirements**	Other studies model **low or no firmness requirements for the hydrogen system and its downstream application** (e.g., liquefaction) – they assume a system that meets an overall annual target with no production requirements on an hourly or daily basis (e.g., a 50% utilization is assumed to be achievable by operating only certain days or months) Several downstream operations (e.g., chemical production) require **consistent hydrogen availability on an hourly or daily basis;** higher firmness requirements usually lead to higher LCOH due to larger storage requirements and optimal sizing of the renewables and electrolyzer
2	**Missing components in assumed capex and opex for hydrogen projects**	Studies tend to consider **only the capital costs associated with the electrolyzer stack**, overlooking **additional costs** of the balance of plant, hydrogen storage, and EPC, as well as other post-gate downstream costs such as liquefaction and distribution. This results in cost assumptions being far too aggressive and LCOH results not representing the actual cost of production
3	**Cost and risk of shaping clean power not fully incorporated**	With hourly time-matching requirements, associated power prices will further increase due to the **additional cost (e.g., energy storage or RES project oversize) and risks (e.g., financial) of shaping power into the profile required** for electrolyzer operations. System models that use top-down approaches smooth out project-level variability impact overlooking the extra cost implications; these increased power prices constitute only a portion of LCOH cost, which does not increase proportionally to the increase LCOE cost
4	**Only "winning" archetypes seem to be modelled**	**Usually, only regions with optimal complementary solar and wind resources are modelled**; these regions represent an archetype that would not be as strongly affected by hourly time-matching and strict local geographic matching requirements; in **reality, hydrogen producers could set up operations elsewhere** (e.g., Camden GA, Fresno CA) which may be less endowed with naturally high quality and complementary resources

Source: Ricks, Wilson, & Jenkins, Jesse. (2023), The Cost of Clean Hydrogen with Robust Emissions Standards: A Comparison Across Studies

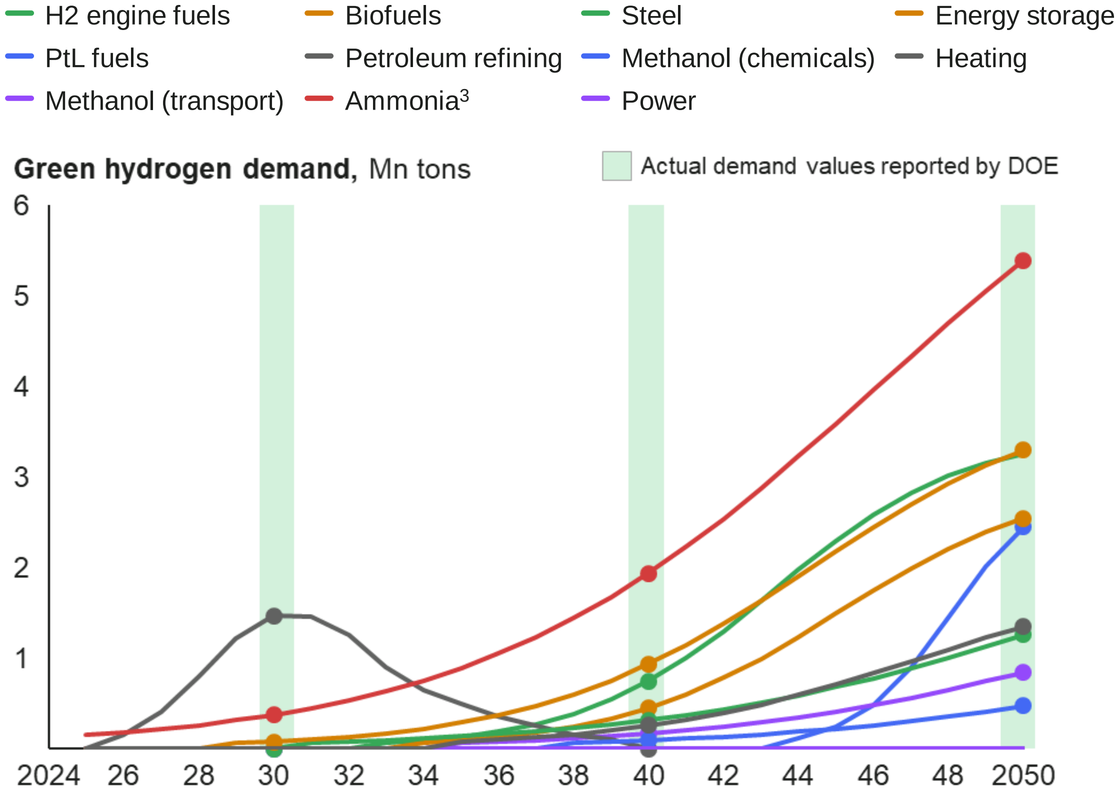
Two critical aspects overlooked by other studies include *realistic* all-in hydrogen costs and the anticipated demand curves

Breakdown of additional costs comprising the total production-to-delivery cost, for plant in GA in 2025, $/kgH2



- **Baseline LCOH often would not reflect the full costs on hydrogen project developers**
- In some cases, even the baseline LCOH reported in public studies excludes additional costs that should be included in the optimization.

Interpolated baseline demand curves by end-use sector

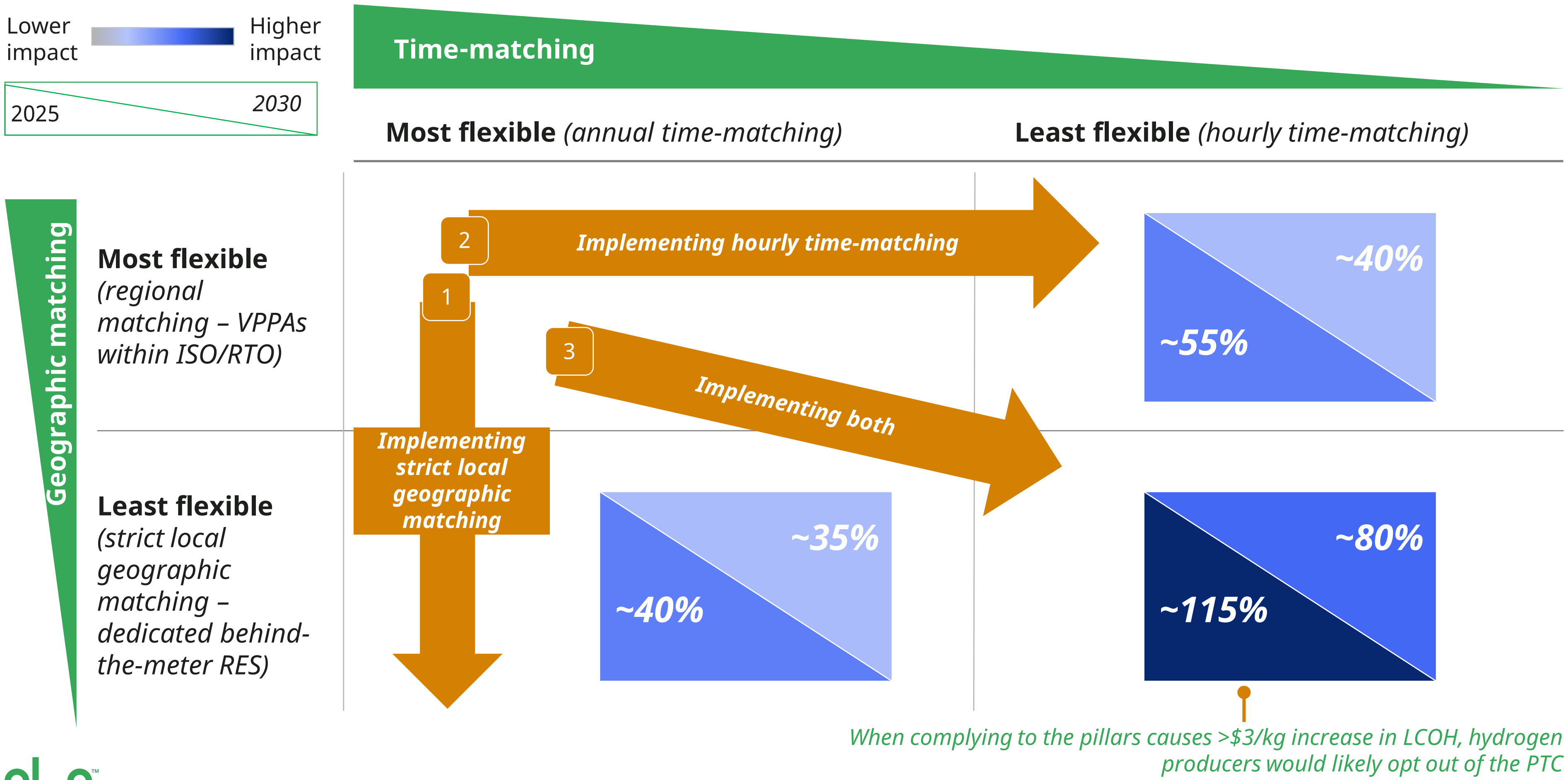


- **2030, 2040, and 2050 base case demand** interpolated from DOE's National Hydrogen Strategy and Roadmap.
- **Immediate scale up is needed** to meet projected levels of demand in 2030+.

Source: Hydrogen cost optimization model, Plug Power inputs on plant costs for first generation plant
For grid electricity, a flat price profile is modelled, and grid prices are taken as they are **(i.e., excluding any cost optimization or negotiations that individual project developers might have)**

Analysis suggests that introducing hourly time-matching and strict local geographic matching immediately could potentially counter the benefits of PTC

Impact of PTC requirements on LCOH, *average across different US regions[1], % of PTC value of $3/kgH2*



- **Hourly time-matching potentially has higher impact on LCOH than strict local geographic matching**, increasing production costs by up to 55% of PTC value if implemented in 2025
- **Implementing both requirements by 2025** could increase LCOH by more than $3/kgH2, **countering the benefit of the PTC**

1. Considering both regions with ample renewables resources (e.g., Texas, Georgia) and regions with ample solar but uncomplimentary wind resources (e.g., California).

Source: Hydrogen cost optimization model.

Hourly time-matching and strict local geographic matching could potentially lead to reductions in gross investments, jobs, and emissions

Gross[1] impact on economic and environmental factors, taking average of LCOH changes across different US regions

Values correspond to 2032 for investments made (final year for PTC eligibility), 2035 for jobs[2], 2040 for green hydrogen demand and emissions abatement loss

Green hydrogen demand | Investments made | Direct and indirect jobs created | Cumulative additional emissions from lost abatement

	Annual time-matching	Hourly time-matching
Regional matching – VPPAs within ISO/RTO	~5 Mn tons ~$12Bn ~560K N/A *(reference case)*	~1.2 Mn tons ~$4Bn[3] ~55k +540Mn tCO2eq; +4.2 microgram/m3 of PM2.5
Strict local geographic matching – dedicated behind-the-meter RES	~2.5 Mn tons ~$4Bn[3] ~220k +460Mn tCO2eq; +4.1 microgram/m3 of PM2.5	~1.1 Mn tons ~$4Bn[3] ~45k +540Mn tCO2eq; +4.3 microgram/m3 of PM2.5

1 +$1/kg LCOH

2 +$1.3/kg LCOH

3 +$2.9/kg LCOH

1. Gross impact considers the impact on the green hydrogen economy only, without considering other clean energies that could potentially replace green hydrogen to back-fill decarbonization needs.
2. Only direct and indirect jobs.
3. Corresponds to the historically announced investments into green hydrogen production in the US, for projects with Commercial Operation Date by 2026.

Source: Plug Power analysis

Introducing both requirements in the near-term would drive up the LCOH by >100% of PTC value and thereby impacting incentive value

Cost increase in LCOH, driven by introducing both strict local geographic matching and hourly time-matching requirements

Lower impact — Higher impact

Detailed next

Impact of strict local geographic matching and hourly time-matching on LCOH

		2023	2025	2030
Average across all archetypes		+5.47	+3.33	+2.37
Archetype A Georgia	Areas with scarce RES assets today	+4.40	+2.70	+1.70
Archetype B Texas	Areas with ample RES assets	+4.20	+2.80	+2.10
Archetype C California	Areas with uncomplemented solar resources	+7.80	+4.60	+3.30

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Introducing both hourly time-matching and strict local geographic matching requirements **could increase LCOH by more than the value of the PTC** in the near term (2025-28)

PTC As-Written

~5 Mn tons

~$12Bn

~560K

N/A
(reference case)

PTC with 100% hourly matching + regionality

~1.1 Mn tons

~$4Bn[3]

~45k

+540Mn tCO2eq;
+4.3 microgram/m3 of PM2.5

Green hydrogen demand

Direct and indirect jobs created

Investments made

Cumulative emissions not abated

Source: Hydrogen cost optimization model

Compounding hourly time-matching with strict local geographic matching could potentially lower the impact of the PTC, if implemented in 2035

Impact of PTC on helping green hydrogen become competitive with conventional fuels

🗓 Hourly time-matching

🌐 Strict local geographic matching

● Green hydrogen becomes competitive as a result of the PTC

○ Green hydrogen does not become competitive as a result of the PTC

Year of implementing pillars		A 2025			2030			2035		
Pillars implemented		**None**	🗓	🗓 + 🌐	**None**	B 🗓	🗓 + 🌐	**None**	🗓	C 🗓 + 🌐
Increase in LCOH[1], % of PTC		-	*40%*	*90%*	-	*30%*	*50%*	-	*28%*	*42%*
Transport	**H2 engine fuel**	●	○	○	●	●	○	●	●	○
	PtL fuels	●	○	○	●	○	○	●	○	○
Depends on vehicle type	**Biofuels**	●	○	○	●	●	●	●	●	●
	Methanol	●	○	○	●	○	○	●	○	○
Industry	**Petroleum refining**	●	○	○	●	●	○	●	●	○
	Ammonia	●	○	○	●	●	○	●	●	●
	Steel	●	○	○	●	●	○	●	●	○
	Methanol	●	○	○	●	○	○	●	○	○
Power & utilities	**Power (H2 turbines)**	○	○	○	○	○	○	○	○	○
	Energy storage	●	○	○	●	●	○	●	●	○
	Heating	●	○	○	●	○	○	●	○	○

A Implementing any of the pillars **in 2025** could potentially increase LCOH to the extent that **green hydrogen producers would opt out of the PTC**

B If hourly time-matching is implemented around **2030-2035, the PTC would still not benefit many end-use sectors**

C **If hourly time-matching and strict local geographic matching are both implemented**, the compounded effect would **negate the benefit of the PTC across almost all sectors**, even if they are implemented in 2035

1. Compared to scenario if pillars are not implemented.

Source: Plug Power analysis

The "three pillars" being considered for implementation would severely impact the rate at which PTC ramps-up the green hydrogen economy

PTC pillars	Definition, *and impact driver*	Implication (based on analysis by Plug)
Additionality	Green hydrogen to be produced using **newly-built clean energy assets** constructed primarily for this purpose ***Reduces the pool of potential sources of clean power*** *to deploy green hydrogen projects*	Additionality makes **renewable power a value chain control point**, **limits business models** that would reduce decarbonization costs, and **reduces benefits of green hydrogen** as a source of power flexibility; given long interconnection queues for renewables, it will likely **delay green hydrogen projects by +5 years** as projects wait for new power sources to materialize This delay from additionality **alone** could impact **~50% of expected new jobs and emission reduction impacts**
Hourly time-matching	Clean power used for electrolyzer operation to be **produced in the same hour it was consumed** ***Increases cost of clean power supply,*** *given the variable nature of most clean power sources (e.g., solar) and the risk and cost of "shaping" it*	Implementing 100% hourly time-matching **alone** in the near-term could **increase green hydrogen production costs by ~$1.3/kg** (roughly ~50% of the value of the PTC); this impact can be reduced over time due to tech cost reductions but still has a significant impact by 2035 Impacts would **decrease green hydrogen investments ~65%** in 2032, create a **~90% loss of gross[1] jobs** in 2035, **reduce green hydrogen demand 75%** in 2040, and push additional gross emission by ~**540Mn tCO2eq of GHG** (~8% of US in 2021) and ~**4.2 micrograms/m3 PM2.5** (~80% of WHO targets) by 2040
Strict local geographic matching	Green hydrogen production to be at **minimum geographic proximity and grid connectivity** from the source of clean power (e.g., direct connection) ***Limits the available sources of power*** *that can be leveraged, driving up cost*	Implementing strict local geographic matching **alone** could **increase green hydrogen production costs by ~$1/kg** (roughly ~35% of the value of the PTC); this impact can be reduced over time due to tech cost reductions, but still has a significant impact by 2035 Implementing both strict local matching and 100% hourly time-matching **in 2025 could increase LCOH to the extent that green hydrogen producers would opt out of the PTC;** compounded impact continues to fully offset PTC beyond 2035

Implementing the three pillars would only serve to delay green hydrogen production scale up and encourage producers to not pursue the PTC at all.

Source: Inflation Reduction Act, Plug analysis

FAQs

FAQs (1/11)

			Question	Answer
LCOH modelling	**Method-ology**	1	How does the model calculate LCOH (levelized cost of hydrogen)?	• We use a linear optimization model at hourly resolution where the objective function is total levelized costs for investment and operations over the plant lifetime, with constraints on target production, firmness of output H2, time matching requirements (hourly vs annual) etc. • In addition to the constraints, inputs include hourly renewables capacity factor profiles (across 8760 hours), grid prices, and financial assumptions (capex, opex, and WACC[1]) for the electrolyzer, H2 storage, RES, etc. • The model then solves for the sizes of all plant components (i.e., power mix supply of solar vs wind vs grid, sizing of electrolyzer, tank, etc.) that delivers the H2 required at lowest cost while compliant to operational constraints
	System setup	2	What is "firmness" target?	• Firmness target refers to the consistency of the profile of produced hydrogen • Each type of hydrogen end-use requires a different level of “firmness”, for example: – If the produced hydrogen is injected into the pipeline or stored in a tank, hydrogen production could be intermittent, hence “firmness” is low – On the other hand, if the produced hydrogen is sent to a liquefaction plant or used for ammonia production, a more consistent flow of hydrogen is needed since those facilities cannot ramp up and down, hence high “firmness” would be required
		3	What specific hydrogen production target is considered in the analysis? Would LCOH decrease with economies of scale?	• We used a sample production of 30 tons/day to model real plant sizes • Economies of scale associated with solar cells, wind turbines, and electrolyzer are embedded into their capex assumptions, hence varying the production target does not impact our results of the optimized production LCOHs

1. Weighted averae cost of capital

FAQs (2/11)

			Question	Answer
LCOH modelling	System setup	4	What is assumed is done with excess electricity?	• It depends on the time-matching requirement: – For annual time-matching, the excess electricity is either curtailed or sold back to the corresponding grid that the plant is interconnected with – For hourly time-matching, the excess electricity is curtailed • In our modelling setup, we assume that excess electricity cannot be sold back to the grid in hourly time-matching scenarios in order to remove the impact of additionality on LCOH results, since interconnection queue would delay COD (commercial operating date) of an asset by 5+ years
		5	How are the locations (i.e., load profiles) from which VPPAs[1]/ PPAs are sourced selected?	• A geospatial model is used to determine the location(s) with the highest average capacity factors and the most complementary profiles, leveraging public solar and wind weather data • For VPPAs, the location(s) are searched for within the ISO/RTO[2] the hydrogen plant is located in; for PPAs, the location(s) are searched for within the county the hydrogen plant is in
	Cost assump-tions	6	Why are flat grid prices used?	• The same market participant assumed grid pricing from publicly available EIA data is used when modelling 2025 and 2030 to isolate the impact of the three pillars on LCOH, without the potential additional impacts of other variables such as grid price
		7	How are VPPA/ PPA prices calculated?	• Using the geospatial model mentioned in the response to Q5 and solar/ wind cost assumptions from NREL[3], solar/ wind LCOEs are calculated and input into the LCOH optimization model as VPPA/ PPA prices

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1. Virtual power purchase agreement; 2. Independent System Operator/Regional Transmission Organization; 3. National Renewable Energy Laboratory

FAQs (3/11)

LCOH modelling	Cost assump-tions	8 What is included in the green hydrogen plant cost assumptions? Why are the costs higher than those cited in other public studies?	• Our green hydrogen plant cost assumptions include system capex (electrolyzer, balance of plant, hydrogen tank storage), as well as EPC • Most of the other public studies tend to use only electrolyzer cost; we include balance of plant, hydrogen tank storage, and EPC[1] costs derived from Plug Power's industrial expertise
		9 What is driving the reduction in electrolyzer and renewables capex over time?	• Technology cost reduction follows the learning curves published by the DOE in their “National Hydrogen Strategy & Roadmap” and “Pathways to Commercial Liftoff” reports; cost reduction is driven by R&D as well as economies of scale across the supply chain associated with building larger plants
	LCOH results	10 How are the results of the modelling higher than those cited in other public studies?	• Four key parameters drive the difference between our analysis and other public studies: – Other studies assume no electrolyzer operational requirement (i.e., zero “firmness”), when in fact several major downstream uses of hydrogen today require consistent hydrogen availability on an hourly basis – Studies tend to consider only the capital cost of the electrolyzer, overlooking costs of balance of plant, hydrogen storage, EPC, etc. – The cost of shaping power into the profile required for electrolyzer operation is not incorporated in other studies; our modelling implicitly incorporates this cost by assuming that consistent hydrogen availability on an hourly basis results in the buildout of storage, larger renewables, and/or electrolyzer capacities, and more realistic electrolyzer utilization – Other studies tend to run LCOH modelling for locations with optimal solar and wind resources; in reality, projects could be located close to hydrogen demand centers, where renewables resources might not be optimal

1. Engineering, procurement, and construction

FAQs (4/11)

LCOH modelling | **LCOH results**

11 What are the specific impacts to the optimization and modeling from hourly time matching that then resulted in the increase in LCOH?

- For annual to hourly comparison, the key factors that increase the LCOH are:
  - ~30% average increase in electrolyzer capacity and hence costs, given electrolyzer will not be functioning all hours and hence need for higher outputs in the hours the electrolyzer functions and
  - ~10-40+ tons of extra storage tank capacity installation, in order to account for hydrogen firmness to ensure reliable outputs for hydrogen end uses
- Please note, the above numbers would vary by region. For example, in TX, the LCOH increase will not be as high as a plant in Georgia or California, where the increases are expected to be much higher

12 What are the specific impacts to the optimization and modeling from regionality/geographic matching that then resulted in the increase in LCOH?

- Key factor that increases the LCOH is that grid prices are higher, given optimizing for renewables power in a smaller region v/s more broadly, say within the ISO/ RTO. The impact of this varies by region.
  - For regions with more complementary RES resources, the impact on LCOH is lower than other archetypes, but could potentially still erode ~15% of PTC value
  - For regions with mostly solar resources and low complementary wind, the impact on LCOH could be large enough to nullify >50% of PTC benefit

1. Engineering, procurement, and construction

FAQs (5/11)

Green hydrogen demand and supply

	Question	Answer
13	Where do the clean and green hydrogen demand numbers come from?	• The clean hydrogen demand numbers are from the base case scenario in the DOE's "National Hydrogen Strategy & Roadmap" • To isolate the green hydrogen demand specifically, the hydrogen demand split by color is used from the Hydrogen Council's "Global Hydrogen Flows" report • Combining the overall clean hydrogen with the green hydrogen %, green hydrogen demand is then calculated for 2030, 2040, and 2050
14	Where do the annual green hydrogen demand numbers come from, if the DOE only reports demand in 2030, 2040, and 2050?	• Green hydrogen demand is assumed to follow an S-curved shape • Hence, yearly green hydrogen demand for each end use is interpolated using a logistic function "A+[(A+B)/(1+(C/x)^n)]", where A=demand starting point, B=demand ending point, x=individual year, n=curvature number; excel solver is used to optimize the curve parameters
15	How is each sector's sensitivity to LCOH calculated?	• For each end use sector, green Hydrogen breakeven year before and after the rollout of Inflation Reduction Act (from the DOE's "Pathways to Commercial Liftoff" report) and the corresponding $3/kg PTC are combined to calculate the sector's breakeven sensitivity to a $/kg chance in LCOH • For end uses that are not mentioned in the report, academic research and team analysis are combined to estimate the sector's breakeven sensitivity based on how much the total ownership cost is dependent on hydrogen production costs vs infrastructure costs

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FAQs (6/11)

Green hydrogen demand and supply	16	Why does the green hydrogen demand from oil refineries occur in earlier years but disappear over time?	• According to the clean hydrogen demand projections published publicly, the economy is expected to move away from diesel as clean alternatives emerge, and hence conventional refineries are expected to phase out by 2040, and the corresponding demand they drive to diminish as well
	17	Why would interconnection queues cause delays in green hydrogen supply? Couldn’t behind-the-meter assets compensate for that?	• Even for green hydrogen production plants with dedicated behind-the-meter renewables, connection to the grid would be important to provide a backup power source to ensure system reliability • Furthermore, behind-the-meter renewables assets could be appropriate for small-scale hydrogen production applications; the full scale-up of the green hydrogen economy might be challenged by pure behind-the-meter resources
Investments	18	Does the investment value include investments across the full hydrogen value chain (i.e., required energy, refueling infrastructure, etc.)?	• No, the investment value only includes the investment needed to build up new green hydrogen facilities, i.e., electrolyzer and hydrogen storage capex and EPC • There would be additional investments lost associated with upstream steps of the value chain (e.g., renewables) and downstream steps (e.g., end use applications); those are not quantified in this study
Jobs	19	What is the methodology behind job calculation?	• Direct jobs are calculated based on cost assumptions and job multipliers that Plug Power has modelled out • Indirect jobs are then estimated using their corresponding job multipliers, adjusted for double-counting effects • Finally, induced jobs are calculated by estimating direct and indirect employee spending

FAQs (7/11)

Jobs

	Question	Answer
20	Where do the job multipliers come from?	• Common job multipliers are from the Economic Policy Institute (2019) • Net multiplier calculation methodology comes from the University of Groningen's "On the Dynamics of Net versus Gross Multipliers" (2002) • Total requirements matrix (to eliminate double counting) is from the U.S. Bureau of Labor Statistics
21	Does the calculated job impact correspond to direct, indirect, or induced jobs?	• The total job impact communicated includes direct and indirect jobs only • Induced jobs are excluded to reflect the gross impact of reduced green hydrogen demand; induced jobs would be considered within net job impact
22	Are the jobs attributed to specific region or hydrogen project?	• The jobs considered reflect the impact on the entirety of the US, since our impact modelling is based on total US demand for green hydrogen

23	Are the calculated jobs associated with only the build-out of the production facilities, or are end-use applications considered as well?	• The jobs considered are across the entirety of the green hydrogen value chain:
		  • Upstream: renewable energy, hydrogen equipment manufacturing, hydrogen production
		  • Midstream: hydrogen distribution and storage
		  • Downstream: end-use applications (e.g., hydrogen engine OEMs, steel plant operators, power plant operators

FAQs (8/11)

Emissions

24	How is emission abatement calculated?	• The net emission impact is calculated by assuming that the lost green hydrogen demand would then lead to conventional fuels to be used for a longer period of time; then the carbon intensity of this conventional fuel is multiplied by the additional conventional fuel consumption to calculated associated emissions • The carbon intensity scores come from a variety of public sources, such as the GREET model, the LCFS Fuel Pathways database, and the US Environmental Protection Agency • This is applied to each end use sector separately, as each sector is characterized by a different conventional fuel and different carbon intensities
25	Are these emissions only from the production of hydrogen, or do they consider the full value chain?	• The net emission impact corresponds to the full value chain, from hydrogen production to its consumption (and hence the replacement of conventional fuels at the point of end use)
26	How does this emissions assessment vary from those conducted in other reports?	• Other studies tend to consider the emissions from hydrogen production only, while we also consider the net benefits of using hydrogen to decarbonize end-use applications, as the legislation intended
27	How are emissions considered for other industries where hydrogen is not used as a fuel, e.g., steelmaking or ammonia?	• For these industries, the emissions abated through the use of green hydrogen correspond to those emitted during the production of hydrogen, i.e., by using green hydrogen vs gray hydrogen for ammonia production, the abated emissions are those from the extraction and reforming of natural gas

FAQs (9/11)

Emissions

28 What is PM2.5?

- According to the US Environmental Protection Agency:
  - PM stands for particulate matter; and PM2.5 are fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller
  - Most particles form in the atmosphere as a result of complex reactions of chemicals such as sulfur dioxide and nitrogen oxides, which are pollutants emitted from power plants, industries and automobiles
  - PM can be inhaled and cause serious health problems. Some particles less than 10 micrometers in diameter can get deep into your lungs and some may even get into your bloodstream. Of these, particles less than 2.5 micrometers in diameter, also known as fine particles or PM2.5, pose the greatest risk to health

29 How is the increase in PM2.5 air pollution concentration calculated?

- First, baseline PM2.5 emissions are calculated by combining the emission factor of a fuel across the value chain (e.g., for diesel: crude oil extraction, refining, transportation, then finally diesel combustion) with the corresponding fuel consumption associated with green hydrogen
- The lost volume of abated PM2.5 is then calculated by subtracting emissions associated with hydrogen use or hydrogen-based fuels (e.g., synthetic diesel) from the baseline pollution level
- To convert lost volume of abated PM2.5 (in tons) into increase in air pollution concentration (microgram/m3):
  - The US atmospheric volume is estimated by dividing total earth atmosphere with US surface % of the Earth
  - Finally, the lost volume of abated PM2.5 is multiplied by an average settling factor of 50-60%, then divided by the US atmospheric volume

FAQs (10/11)

Emissions

30 What is your response to studies which claim that the PTC will result in significant increases in grid emissions?

- The studies claiming that the PTC will drive significant increases in grid emissions are compounding several poor assumptions and limitations of their models.
- These studies assume the following:
  - The grid is uniformly dirty everywhere (using the highest emissions intensity available)
  - They are looking at a static point in time and fail to consider that the grid emissions intensity will improve as more renewables are deployed, fossil assets retired, and existing fossil assets cleaned up.
  - They assume that all other (non-IRA) state and federal climate policies are ineffective.
  - They assume that electrolyzer plants will not be able to get any access to RECs or other green electrons, requiring them to run on grid power 100% of the time.
- Under all of these assumptions, yes, the models showing grid emissions increasing due to increased electrolytic hydrogen load are not incorrect. **However, this is a model of a highly unrealistic scenario.**
- The grid has been getting cleaner for the last 15 years and will continue to do so.
- Significant renewable assets are in the interconnect queue, in addition to those already available.
- State and Federal policies (i.e., IRA) are projected to rapidly accelerate renewable deployment, resulting in the grid emissions to further decrease.
- Green hydrogen producers will not be using 100% grid power; rather, it would only be considered at discrete moments in time to firm an operation.
- The emission numbers arrived at in some of those studies also fail to consider the potential abatement. The hydrogen would actually be used to decarbonize an application, resulting in an emissions benefit.
- These studies are not wrong, they are just being poorly applied and interpreted.

FAQs (11/11)

Emissions

31 If additionality is not imposed what would be the emissions associated with production if electrolytic load is added to the grid?	• At present, 100% grid powered electrolysis (not what is being proposed by Plug) does have more emissions than SMR produced (grey) hydrogen by ~2x. • However, as the grid gets cleaner this dynamic will change. Depending upon the application, grid produced hydrogen would be "cleaner" than SMR by ~2030. RMI has an excellent calculator projecting this based upon various scenarios. • This aligns with when the large green hydrogen demand is projected to be required.

Green Hydrogen at Work™