**DOE Alternative Fuels and Feedstocks Office Program Record**

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# **Title:** Water Use in Hydrogen Production

**Originators:** Marc Melaina, Michael Penev, Benjamin Zavell, Arti Khanal, Mariya Koleva

**Peer Reviewers:**

Keith Ambrose, Electric Power Research Institute
Zach Batts, Apex Clean Energy
Emanuele Bianco, Asian Development Bank
Pallavi Bobba, Electric Power Research Institute
Matthew Gacek, Southwest Research Institute
George G. Zaimes, U.S. DOE, Office of Fossil Energy
Matthew Jamieson, National Energy Technology Laboratory
Page Kyle, Pacific Northwest National Laboratory
Eric Lewis, National Energy Technology Laboratory
Ishan Pandey, Argonne National Laboratory
Lorenzo Rosa, Carnegie Science
Minish Shah, Linde
Brittany Westlake, Electric Power Research Institute
Patricia Wild, International Renewable Energy Agency
Xinran Zhou, Lawrence Berkeley National Laboratory

**Approved by:** Neha Rustagi
**Date:** 04/07/2026

## Item

This record estimates water use for five commercial hydrogen production processes:

- Steam methane reforming (SMR) of natural gas (the main process used today);
- SMR of natural gas with carbon capture and sequestration (CCS);
- Electrolysis using electricity from nuclear;
- Electrolysis using electricity from solar; and
- Electrolysis using electricity from wind power.

Including both direct and indirect consumption, the production of 10 million metric tonnes of hydrogen per year (current demand) by any of the production methods evaluated would require less than 2% of total U.S. water consumption today.[1]

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[1] Current total water consumption is estimated based on 2015 water consumption for agriculture and power generation sectors (the most recent year reported, USGS 2018).

## Background

Hydrogen can be produced commercially from natural gas steam methane reforming, electrolysis, and a number of additional processes, including pyrolysis, drilling for geologic hydrogen, coal or biomass gasification, as well as more advanced methods with lower technology readiness levels, such as biological and photoelectrochemical production pathways.[2] This record estimates water consumption and withdrawal intensities, in units of gallons of water per kilogram of hydrogen[3] (gal $H_2O$/kg $H_2$), for five pathways: natural gas SMR, natural gas SMR with CCS, and proton exchange membrane (PEM) electrolysis with electricity from three sources of electricity: light-water nuclear reactor (LWR) power plants, photovoltaic (PV) solar power, and wind power. Other hydrogen production pathways may be addressed in future work.

Water use terminology in this record includes the following (see Figure 1):

- **Direct water use.** Water used at the hydrogen production facility (also called onsite use). This use is most relevant for estimating local water stress impacts.
- **Indirect water use.** Water used by processes occurring upstream of the hydrogen production facility, such as natural gas supply and electricity generation, as well as water use in equipment manufacturing and material supply, which may occur in other countries.
- **Withdrawn water.** All water removed from a water source and subsequently either consumed or returned to the local watershed.
- **Consumed water.** Water withdrawn from a water source and not returned to the local watershed, typically because the water has been chemically converted or evaporated. Water consumption is a subcategory of water withdrawn.

In general, within the energy sector, total water withdrawals are roughly 7-10 times greater than total water consumed, with electricity generation accounting for the majority of water withdrawn (UN 2024; IEA 2023; USGS 2018). While both consumption and withdrawals are estimated, the present record focuses on direct water consumption at the production facility, which is most directly dependent upon production technology performance, such as conversion efficiency. For additional discussion of water stress related to consumption and withdrawals, see UN (2024) and WRI (2025). While this record assumes all water use draws upon fresh water sources, opportunities exist to recycle water internally or rely on non-freshwater sources, such as industrial wastewater or ocean water desalinization. However, these options are typically accompanied by cost increases to ensure quality (Winter et al., 2022; Iyer et al., 2024; Lin et al., 2025). Similarly, as a means of reducing cooling water requirements, waste heat from hydrogen production could be utilized if co-located with facilities requiring input heat, such as industrial and district heating (Bohm et al., 2021) or desalinization (Arthur et al., 2024). The methods and input data used to estimate water use in energy systems can vary significantly between studies. This record relies

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[2] Some of these production types have water consumption estimates in the GREET model, though they are not directly comparable to the estimates in the present record. For more information on hydrogen production technologies, visit: https://www.energy.gov/eere/fuelcells/hydrogen-production-processes.

[3] Summary results are also reported in liters per kg hydrogen in Table A8.

upon methods, data, and results from multiple previous studies (Lampert et al., 2015; Simoes et al., 2022; Winter et al., 2022; Grubert, 2023; IRENA & Bluerisk, 2023; Tonelli et al., 2023; Ramirez et al., 2023; Saboori et al., 2024; Terlouw et al., 2024).

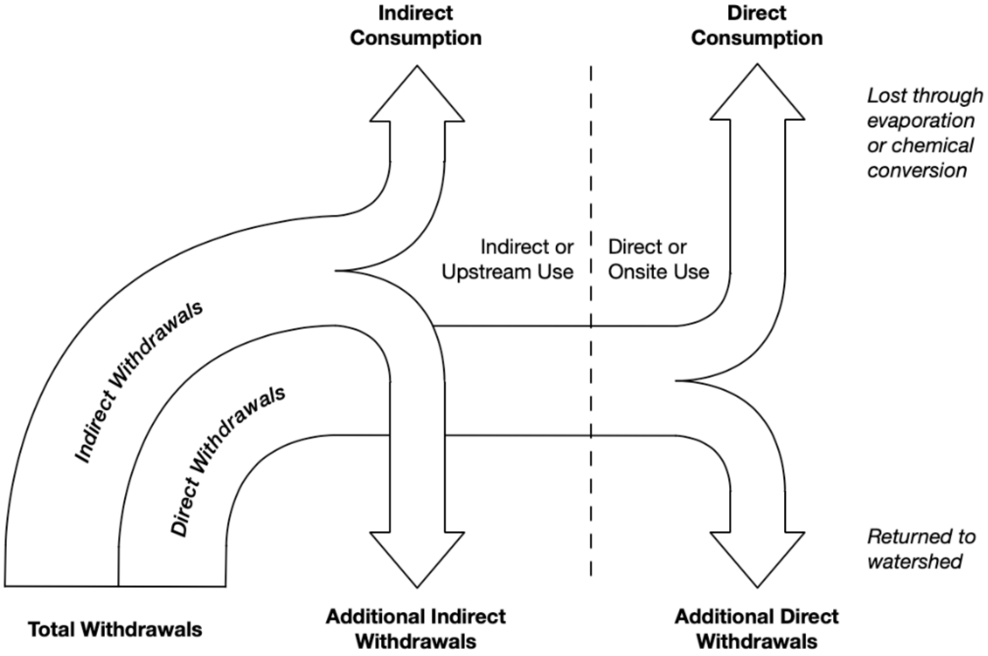

**Figure 1. Breakdown of water use as indirect (or upstream) and direct (or onsite), with total withdrawals being the sum of consumption and additional withdrawals.**

Water consumption and withdrawal estimates are developed for three cases: Minimal, Efficient, and Unlimited. These three cases explore a range of tradeoffs between capital costs, water saving technologies, and cooling technology types, resulting in distinct direct and indirect water use estimates. Any production facility would be designed in response to these and various other project requirements and constraints. The three cases are based upon the same technical assumptions for each of the five hydrogen production technologies, and are primarily characterized in terms of the cooling technology employed:

1. **Unlimited**: Traditional and standardized approach based on cooling tower technology, employed when there are no major local or regional limitations on water availability.
2. **Efficient**: Hybrid cooling employed in response to significant local water restrictions.
3. **Minimal**: Dry cooling employed in response to severe local water restrictions.

The Unlimited case results are expected to be representative of most facilities. This is because the cost of water is typically a small contributor to total operating costs, and because more advanced and efficient cooling technologies tend to introduce a degree of technical and financial risk for most project developers. The Efficient and Minimal cases are relevant for projects responding to significant water consumption constraints, resulting from corporate requirements, regulatory requirements, or other factors. The two sections below discuss assumptions for SMR and electrolysis, followed by a summary of results. Appendices provide additional details.

Because the severity of water stress conditions varies by geography and watershed, the impacts of direct or indirect water use will depend upon the existing water stress of the respective locality or region (for geographic estimates of water stress, see Uisung et al., 2019). Moreover, within the indirect category, electricity production may be very remote from the production facility, and equipment material extraction and manufacturing may be distributed across international supply chains.

### Steam Methane Reforming (SMR) with and without Carbon Capture and Storage (CCS)

SMR is currently the most common process for hydrogen production in the United States. Water use estimates for SMR with and without CCS are primarily based upon R&D GREET 2024 (hereafter referred to as GREET) default values, which are based upon production case studies documented in a 2022 NETL report (Lewis et al., 2022; Zhou et al., 2024). Estimate results for direct and indirect water use are summarized in Tables A1 and A2. For the conventional SMR process, it is assumed that water consumed to produce steam that is not used to make the hydrogen product is then valorized (i.e. “co-product” or “export” steam) and allocated to the steam end-use product or service.[4] Without this allocation assumption, total water consumption for SMR would be 4.2 gal $H_2O$/kg $H_2$, and therefore larger than the electrolysis Minimal and Efficient cases (see Table A3, cf. IRENA-Bluerisk 2023). Process water requirements for SMR with CCS are much less than those for SMR due to condensate recovery. In contrast, cooling water required for SMR with CCS is much higher than SMR without CCS, though this water use is significantly reduced in the Minimal and Efficient cases. Cooling water for the Unlimited case is taken from Lewis et al. (2022), while cooling water for Minimal and Efficient cases are unique to this record. Additional direct withdrawals are required for water treatment (all cases) and cooling blowdown and drift losses (Unlimited only).

Indirect water consumption is associated with natural gas and electricity supply, as well as losses associated with water supply for direct water use. As would be the case with electrolysis units using local grid electricity (not estimated in this record), the water intensity for electricity use in SMR production would vary regionally (Uisung et al., 2019; Reig et al., 2020). SMR equipment manufacturing water consumption is less than 0.005 gal $H_2O$/kg $H_2$ and therefore considered negligible (Iyer et al., 2024); all other direct and indirect system boundary assumptions are parallel to those for electrolysis.

### Electrolytic Production

Many factors can influence water consumption and withdrawal requirements for both direct use at the electrolysis production facility and indirect upstream processes. The current estimates are for PEM electrolysis only, though alkaline electrolysis is also a commercial pathway Most input assumptions are taken from the R&D GREET 2024 model, including water used for electricity

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[4] This assumption is consistent with the default allocation used for greenhouse gas emissions accounting in the 45V version of the GREET model (DOE 2023). The rationale behind this assumption is based upon the fact that most existing SMR facilities involve steam exports, as well as recovery of the steam condensate, which is likely to be returned to the local watershed (c.f., Gonzales-Calienes 2022, Table 6-3).

generation and for the materials and manufacturing processes associated with the electrolyzer and corresponding nuclear, solar PV, and wind power generation equipment (ANL 2025). Water withdrawal estimates are primarily based on EPRI (2012) (cf. Meldrum et al., 2013, Grubert et al., 2018, and EIA 2023).

Estimates include five categories of direct water use (see Table A3 for details):

- **Electrolysis water purification (withdrawal)**. Additional withdrawals to account for the recovery rate of reverse osmosis (RO). Any additional treatment required beyond RO (e.g., ion exchange) is assumed to require no water.
- **Electrolysis reaction (consumption).** Water consumed in the electrolytic conversion of water into hydrogen and oxygen. While not explored in this record, improvements in PEM electrolysis efficiency would result in reduced water consumption (see assumptions in Table A3, and IRENA & Bluerisk, 2023).
- **Vapor losses and condensate (consumption and withdrawal).** Some water entering the electrolysis unit is taken up as vapor contained in the resulting hydrogen and oxygen gas streams. Some of this vapor is lost to the atmosphere and some is subsequently recovered as condensate and recycled. As indicated in Table A3, the amount recovered is slightly larger than the amount lost, resulting in a net reduction in total water withdrawals.
- **Cooling evaporation (consumption).** Water consumed in cooling the electrolysis unit and hydrogen condensers and compressors. The Minimal case assumes dry cooling (no direct water use), the Efficient case relies on hybrid cooling, and the Unlimited case uses cooling towers (see Appendix B).[5,6]
- **Blowdown and drift (withdrawal)**. Additional water withdrawals for cooling tower operation (Unlimited case only). See Appendix B and (FEMP 2024).

Estimates include three categories of indirect water use (see Table A3 for details):

- **Water supply losses (consumption and withdrawal)**. These losses occur during the storage and delivery of municipal water supply to the hydrogen production facility (See Table A5 for details).
- **Electrolysis manufacturing (consumption).** Water use for materials and manufacturing processes associated with the electrolysis unit and balance of plant components.
- **Electricity for electrolysis (consumption and withdrawal)**. This includes upstream water used for cooling thermal electricity production facilities, uranium feedstock supply, and materials and manufacturing for electricity generation equipment (See Table A6).

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[5] For discussions of cooling technology types and issues related to electrolysis, see: Yang et al. (2019), Karimi et al. (2022), Saboori et al. (2024), Lin et al. (2025), Robert & Barear (2024).

[6] Recycling RO effluent to use for cooling water could reduce direct consumption (see Table A3).

## Summary Results

Water consumption results are summarized in Figure 2 as lower and upper bounds on the following: direct water consumed at the production facility, indirect upstream consumption, and total consumption, which is the sum of direct and indirect. The upper bound results shown as diamond symbols with numeric labels are Unlimited case estimates, which are assumed to be the most likely outcomes for most hydrogen production facilities.[7] Minimal and Efficient case results, which require very lower cooling water volumes, constitute the lower bounds of the ranges indicated. As shown, SMR with and without CCS have the lowest water consumption ranges. Numeric results for all cases, including subcategories, are provided in Tables A1, A2, and A3. Direct water consumption for electrolysis (8 gal $H_2O$/kg $H_2$, Unlimited Case) is 25% higher than SMR with CCS (6.4 gal $H_2O$/kg $H_2$, Unlimited Case) and the low end of electrolysis direct water use (2.4 gal $H_2O$/kg $H_2$, Minimal Case) is 16% larger than direct water consumed in the SMR Unlimited case (2.1 gal $H_2O$/kg $H_2$).

The wide variation in indirect water use for electrolysis is based upon distinct characteristics of electricity from nuclear (LWR), solar PV, and wind power. For nuclear, approximately 90% of water consumption is for power plant cooling (consumed through evaporation), ~9% is for feedstock supply (i.e., uranium fuel cycle), and less than 0.1% is from power plant materials and manufacturing. In contrast, 96% and 90% of water consumption is for materials and manufacturing for solar PV and wind power, respectively, with the remaining consumption due to power plant operation. See Table A7 for details.

This assessment estimates that the production of 10 million metric tonnes of hydrogen per year (current production in the U.S.) by any of the production methods evaluated would require less than 2% of total U.S. water consumption today. Figure 3 is a visual comparison of total water consumption required to produce 10 MMT of hydrogen using each of the four alternative production pathways, as a percent of total water consumed for irrigation and thermal power generation, estimated at 77.5 billion gallons per day (irrigation and thermal power generation consume the majority of water in the U.S. today, and are the only sectors with consumption estimates from USGS). These theoretical estimates are intended to capture a range of likely or typical designs and operating conditions in the near-term. Water use in real-world production facilities would vary from these estimates based on factors such as facility design and upstream supply chain. As additional large-scale commercial facilities come online, empirical data can be relied upon to improve future water intensity estimates.

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[7] The Unlimited case is more likely to be typical in the Eastern United States when water scarcity is not a major limitation. However, it may not be as likely in other US regions, especially those with institutional restrictions on water use. It also does not necessarily apply internationally, especially in hot arid regions.

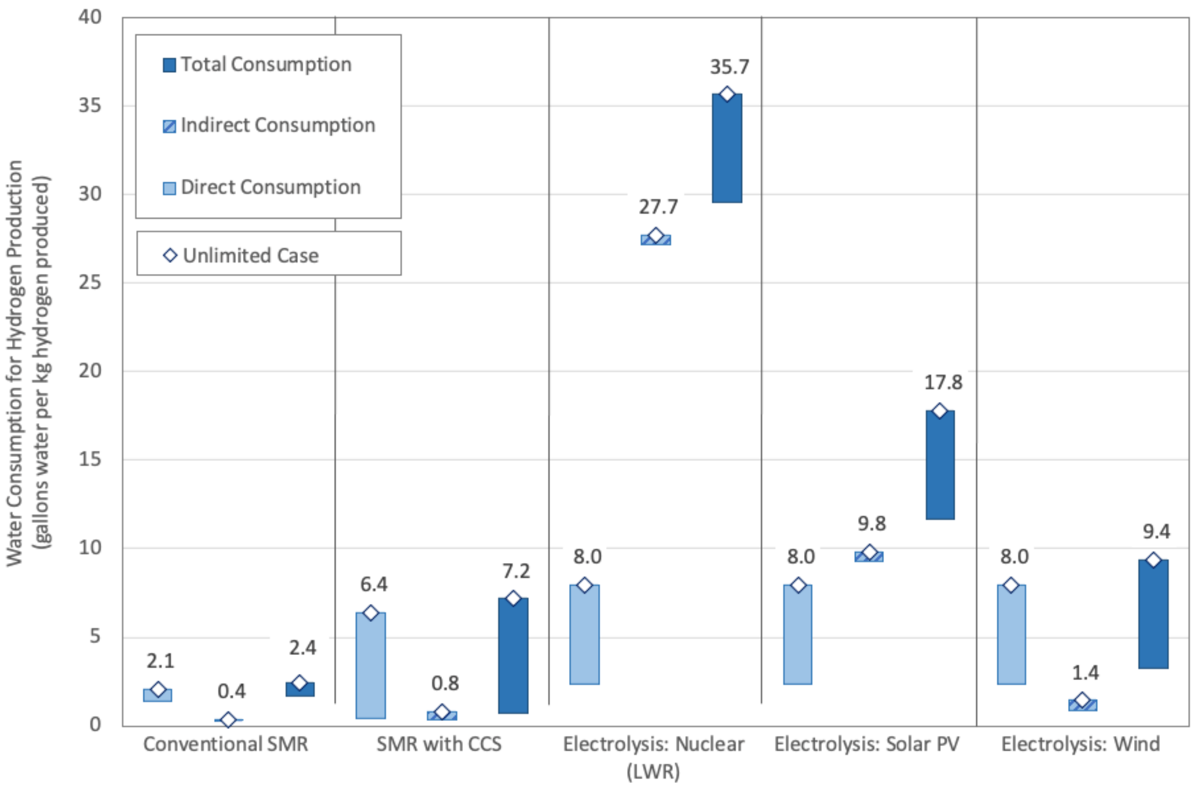
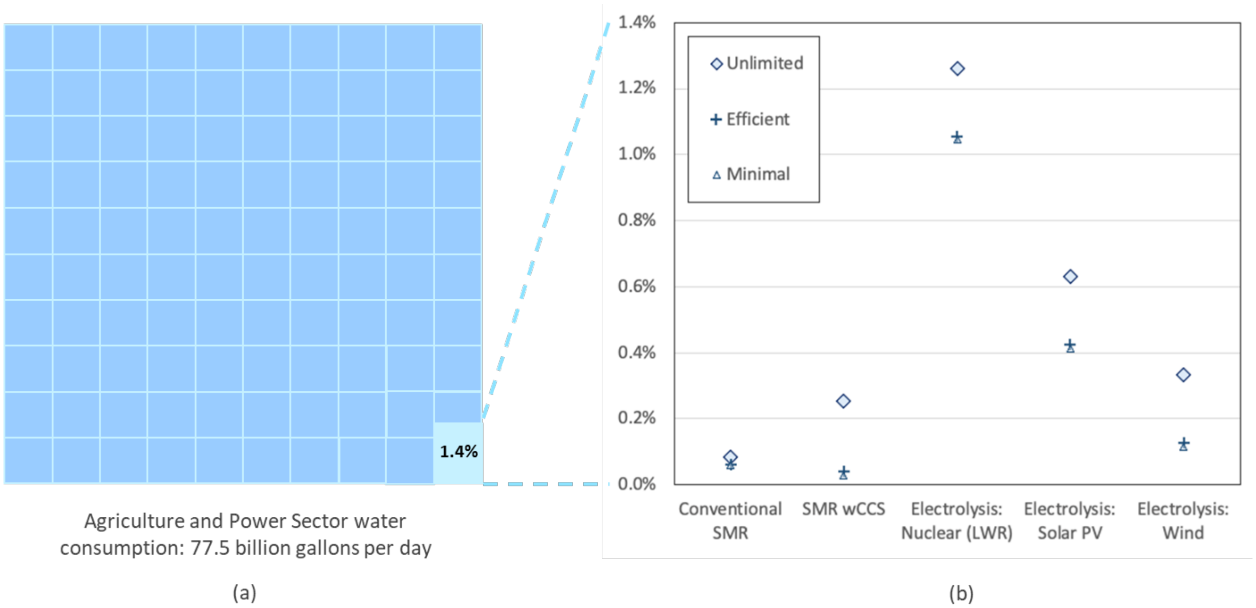


**Figure 2. Direct, indirect, and total water consumption for all production types, not accounting for potential future technologies (e.g. advanced nuclear). Bars indicate ranges between Min/Eff and the Unlimited case results, denoted by diamonds and numbers. Values may not sum due to rounding.**



Agriculture and Power Sector water consumption: 77.5 billion gallons per day

(a)

(b)

**Figure 3. Visual depiction of total water consumption when producing 10 MMT hydrogen from each production type, shown as less than 1.4% of total US agriculture and thermal power water consumption (a), and with Minimal, Efficient, and Unlimited percentage results for each type (b).**

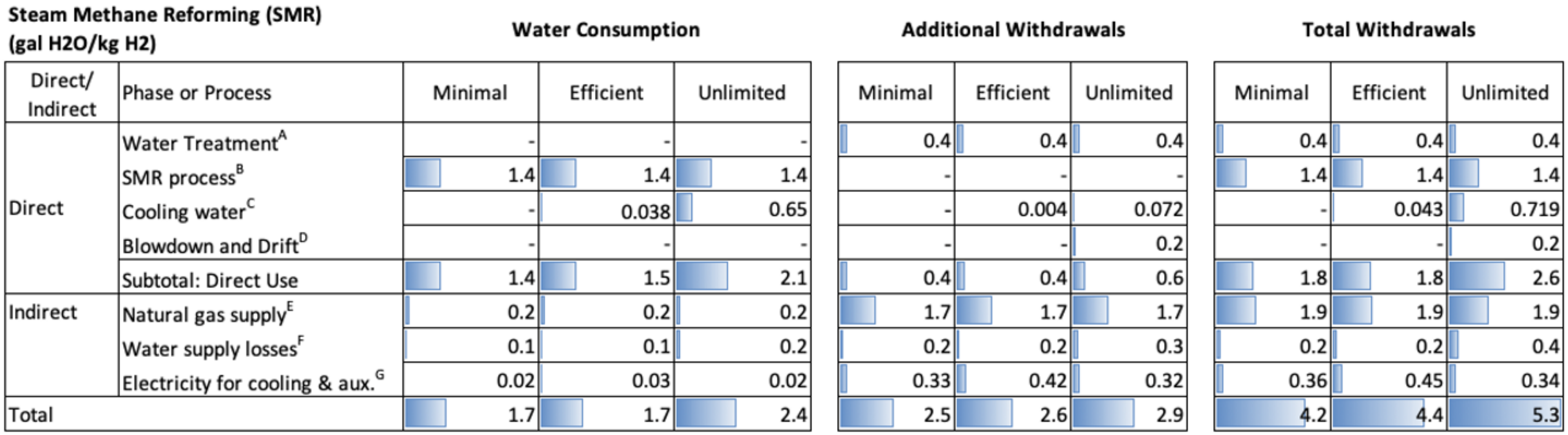
## Appendix A. Additional assumptions and results.

Tables A1 and A2 summarize results for SMR without and with CCS, respectively, and include notes on key assumptions and sources. Assumptions are largely based upon GREET defaults, which are derived from a 2022 NETL report (Lewis et al., 2022). A large portion of water use in this report's SMR system (identified as Case 1) is process steam, at 2.3 gal $H_2O$/kg $H_2$, while water produced and recovered from syngas condensate (0.9 $H_2O$/kg $H_2$) offsets some direct feedstock water consumption. The result is a net consumption of 1.4 gal $H_2O$/kg $H_2$ (Lewis et al., 2022, Exhibit 3-10). While Case 1 from the NETL report includes steam export, it is assumed that water used for export steam is not allocated to the water intensity of hydrogen production, as the steam exported is offsetting steam that would otherwise have been produced for an external consumer. Water evaporated through the cooling tower in the Unlimited case is reported as 0.65 gal $H_2O$/kg $H_2$. The Minimal and Efficient cases use cooling water proportional to that used in electrolysis on a cooling load basis (see Appendix B).

For SMR with CCS, direct consumption estimates are based upon the Case 2 system from Lewis et al. (2022), consisting of reaction process water, cooling makeup water, and water for the CCS system. While the same amount of process steam is required for the SMR reaction, a larger volume of water is produced from syngas condensate, resulting in lower net process water consumption than SMR without CCS (Lewis et al., 2022, Exhibit 3-28). CCS processes use additional steam and requires significant cooling, resulting in increased water use compared to SMR without CCS.

Table A3 summarizes results for electrolytic hydrogen production and includes notes on key assumptions and sources. Water use categories follow those described in the main text, including direct and indirect water consumption and withdrawals. Indirect results associated with electricity generation are broken out for nuclear, solar PV, and wind. Note that the data bars are scaled to magnitude for all results except nuclear additional withdrawals (which are 30x larger than the largest consumption results). Detailed calculations for electrolysis cooling, consistent with GREET, are provided in Appendix B. Because the GREET model only estimates water consumption, assumptions for withdrawals are primarily from EPRI (2012), which can be compared to other sources (Meldrum et al., 2013; Lin et al., 2025; Tonelli et al., 2023) (see Table A6).

Table A4 summarizes direct and indirect consumption, additional withdrawals, and total withdrawal results for all five production types. For each section (consumption, additional withdrawals, and total withdrawals) an additional metric is introduced: the ratio of indirect water use to direct water use. This ratio indicates the proportion of total water use in each category that is indirect vs. direct (upstream vs. onsite). The general trend is for dry and hybrid cooling to decrease indirect water use, though this tendency varies by production type. Note that an increased ratio does not necessarily correspond to an increase in total use.



**Steam Methane Reforming (SMR) (gal H2O/kg H2)**

| Direct/ Indirect | Phase or Process | Water Consumption | | | Additional Withdrawals | | | Total Withdrawals | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Minimal | Efficient | Unlimited | Minimal | Efficient | Unlimited | Minimal | Efficient | Unlimited |
| Direct | Water Treatment[A] | - | - | - | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | SMR process[B] | 1.4 | 1.4 | 1.4 | - | - | - | 1.4 | 1.4 | 1.4 |
| | Cooling water[C] | - | 0.038 | 0.65 | - | 0.004 | 0.072 | - | 0.043 | 0.719 |
| | Blowdown and Drift[D] | - | - | - | - | - | 0.2 | - | - | 0.2 |
| | Subtotal: Direct Use | 1.4 | 1.5 | 2.1 | 0.4 | 0.4 | 0.6 | 1.8 | 1.8 | 2.6 |
| Indirect | Natural gas supply[E] | 0.2 | 0.2 | 0.2 | 1.7 | 1.7 | 1.7 | 1.9 | 1.9 | 1.9 |
| | Water supply losses[F] | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.4 |
| | Electricity for cooling & aux.[G] | 0.02 | 0.03 | 0.02 | 0.33 | 0.42 | 0.32 | 0.36 | 0.45 | 0.34 |
| Total | | 1.7 | 1.7 | 2.4 | 2.5 | 2.6 | 2.9 | 4.2 | 4.4 | 5.3 |

**Table A1. Minimal, Efficient, and Unlimited case estimates for SMR without CCS water consumption, additional withdrawals, and total withdrawals. System boundaries are identical to electrolysis cases, with the exception of excluding water use for SMR equipment.**

A. Reverse osmosis (RO) recovery rates assumed to be 80% for all cases (Lin et al, 2025). Actual recovery rates are highly dependent upon the source water quality and type of RO system.

B. Process water consumption from Exhibit 3-10 of NETL 2022 is the sum of SMR steam and syngas condensate water recovered, but does not include water used to generate exported steam (cf., Lewis et al., 2022).

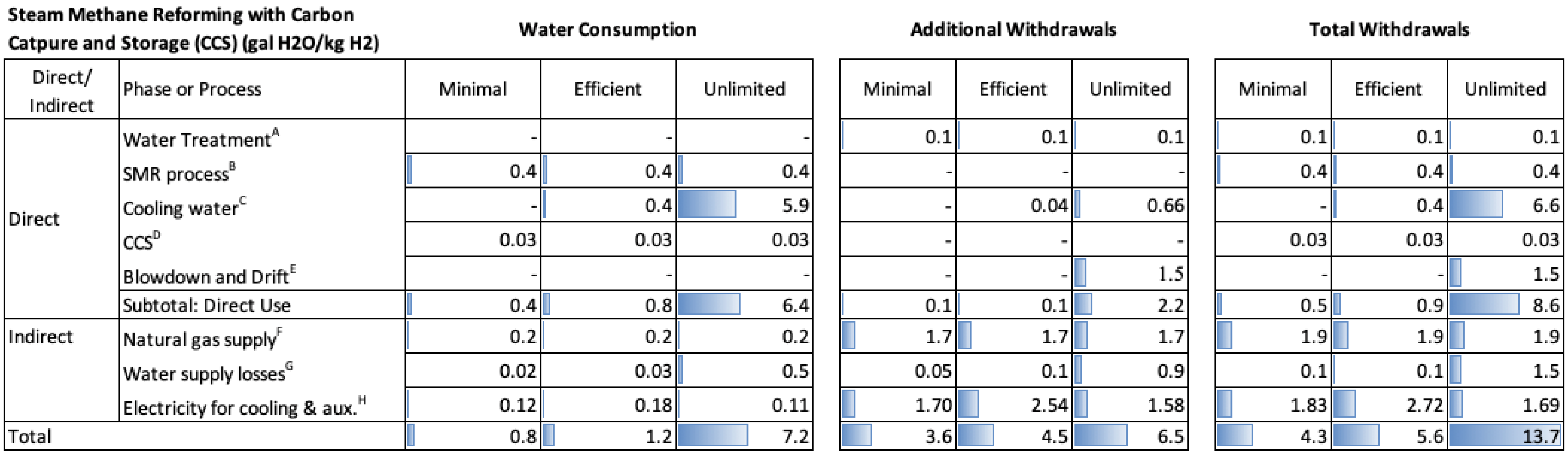
C. Minimal case is dry cooling. Unlimited case uses cooling tower water results from Exhibit 3-10, NETL 2022 (Lewis et al., 2022), which reports ~20% less water than the theoretical cooling tower estimates for electrolysis. Efficient case cooling is proportional to savings in the electrolysis efficient case. Cooling water additional withdrawals are due to input water treatment, assumed to have a 90% recover rate.

D. Proportional to blowdown and drift in the electrolysis Unlimited case, which are based on theoretical equations from Perry's Handbook (Green & Southward 2019). See details for cooling tower losses (Unlimited case only) in Appendix B.

E. Water consumption for natural gas recovery, processing, and transmission and distribution from R&D GREET 2024. Water withdrawals based on EPRI 2012 assuming an average turbine efficiency of 50% to back-calculate to natural gas supply.

F. Water supply losses include those in the supply of municipal water to the production facility, as well as losses during use and water management at the facility. See Table A5 for details from Simoes et al. (2021) and compare with EPA (2024).

G. Electricity required for onsite cooling assumes the same cooling methods as electrolysis and the Case 1 cooling load from Exhibit 3-11 in NETL 2022 (Lewis et al., 2022). Auxiliary power requirement of 0.6 kWh per kg (Case 1, NETL 2022) (Lewis et al., 2022). See 2024 grid mix water use in Table A6.



**Steam Methane Reforming with Carbon Catpure and Storage (CCS) (gal H2O/kg H2)**

| Direct/ Indirect | Phase or Process | Water Consumption |  |  | Additional Withdrawals |  |  | Total Withdrawals |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Minimal | Efficient | Unlimited | Minimal | Efficient | Unlimited | Minimal | Efficient | Unlimited |
| Direct | Water Treatment[A] | - | - | - | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
|  | SMR process[B] | 0.4 | 0.4 | 0.4 | - | - | - | 0.4 | 0.4 | 0.4 |
|  | Cooling water[C] | - | 0.4 | 5.9 | - | 0.04 | 0.66 | - | 0.4 | 6.6 |
|  | CCS[D] | 0.03 | 0.03 | 0.03 | - | - | - | 0.03 | 0.03 | 0.03 |
|  | Blowdown and Drift[E] | - | - | - | - | - | 1.5 | - | - | 1.5 |
|  | Subtotal: Direct Use | 0.4 | 0.8 | 6.4 | 0.1 | 0.1 | 2.2 | 0.5 | 0.9 | 8.6 |
| Indirect | Natural gas supply[F] | 0.2 | 0.2 | 0.2 | 1.7 | 1.7 | 1.7 | 1.9 | 1.9 | 1.9 |
|  | Water supply losses[G] | 0.02 | 0.03 | 0.5 | 0.05 | 0.1 | 0.9 | 0.1 | 0.1 | 1.5 |
|  | Electricity for cooling & aux.[H] | 0.12 | 0.18 | 0.11 | 1.70 | 2.54 | 1.58 | 1.83 | 2.72 | 1.69 |
| Total |  | 0.8 | 1.2 | 7.2 | 3.6 | 4.5 | 6.5 | 4.3 | 5.6 | 13.7 |

**Table A2. Minimal, Efficient, and Unlimited estimates for SMR with CCS water consumption, additional withdrawals, and total withdrawals. System boundaries are identical to electrolysis cases, with the exception of excluding water use for SMR equipment.**

A. Reverse osmosis (RO) recovery rates assumed to be 80% for all cases (Lin et al, 2025). Actual recovery rates are highly dependent upon the source water quality and type of RO system.
B. Process water consumption from Exhibit 3-28 of NETL 2022 as sum of SMR steam and syngas condensate water recovered (Lewis et al., 2022).
C. Minimal case is dry cooling. Unlimited case uses cooling tower water results from Exhibit 3-28, NETL 2022 (Lewis et al., 2022), which reports ~20% less water than the theoretical cooling tower estimates for electrolysis (Appendix B). Efficient case cooling is proportional (on a cooling load basis) to water use in the electrolysis Efficient case. Cooling water additional withdrawals are due to input cooling water treatment assumed to have a 90% recover rate.
D. Net water consumption from CCS processes, Exhibit 3-28 of NETL 2022 (Lewis et al., 2022). Cooling water requirements are included in cooling water.
E. Proportional to blowdown in the electrolysis Unlimited case, which are based on theoretical equations from Perry's Handbook (Green & Southward 2019). See details for cooling tower losses (Unlimited case only) in Appendix B.
F. Water consumption for natural gas recovery, processing, and transmission and distribution from R&D GREET 2024 (ANL 2024). Water withdrawals based on EPRI 2012 assuming an average turbine efficiency of 50%.
G. Water supply losses include those in the supply of municipal water to the production facility, as well as losses during use and water management at the facility. See Table A5 for details from Simoes et al. (2021) and compare with EPA (2024).
H. Electricity required for onsite cooling assumes the same cooling methods as electrolysis using the Case 2 cooling load from NETL 2022 (Lewis et al., 2022). Auxiliary power requirement of 2.0 kWh per kg (Case 2, NETL 2022) (Lewis et al., 2022). See 2024 grid mix water use in Table A6.

| PEM Electrolysis (gal H2O/kg H2) | | | Water Consumption | | | Additional Withdrawals | | | Total Withdrawals | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Phase or Process | | | Minimal | Efficient | Unlimited | Minimal | Efficient | Unlimited | Minimal | Efficient | Unlimited |
| Direct Use | Purification of electrolysis water[A] | | - | - | - | 0.41 | 0.66 | 0.78 | 0.41 | 0.66 | 0.78 |
| | Electrolysis reaction[B] | | 2.4 | 2.4 | 2.4 | - | - | - | 2.4 | 2.4 | 2.4 |
| | Vapor losses and condensate[C] | | 0.03 | 0.03 | 0.03 | -0.04 | -0.04 | -0.04 | -0.01 | -0.01 | -0.01 |
| | Cooling water use and treatment[D] | | - | 0.26 | 5.57 | - | 0.03 | 0.62 | - | 0.29 | 6.19 |
| | Blowdown and Drift[E] | | - | - | - | - | - | 1.4 | - | - | 1.4 |
| | Subtotal: Direct Use | | 2.4 | 2.6 | 8.0 | 0.4 | 0.6 | 2.7 | 2.8 | 3.3 | 10.7 |
| Indirect Use | Water supply losses[F] | | 0.1 | 0.1 | 0.6 | 0.2 | 0.3 | 1.2 | 0.3 | 0.4 | 1.8 |
| | Electrolysis manufacturing[G] | | 0.2 | 0.2 | 0.2 | 0.05 | 0.05 | 0.05 | 0.25 | 0.25 | 0.25 |
| | Electricity for Electrolysis[H] | Nuclear | 26.9 | 26.9 | 26.9 | 1020 | 1021 | 1020 | 1047 | 1048 | 1047 |
| | | Solar | 9.0 | 9.0 | 9.0 | 2.2 | 2.2 | 2.2 | 11.2 | 11.2 | 11.2 |
| | | Wind | 0.6 | 0.6 | 0.6 | 2.8 | 2.8 | 2.8 | 3.4 | 3.4 | 3.4 |
| | Subtotal: Indirect Use | Nuclear | 27.2 | 27.2 | 27.7 | 1020 | 1022 | 1021 | 1047 | 1049 | 1049 |
| | | Solar | 9.3 | 9.3 | 9.8 | 2.5 | 2.5 | 3.4 | 11.8 | 11.8 | 13.2 |
| | | Wind | 0.9 | 0.9 | 1.4 | 3.0 | 3.1 | 4.0 | 3.9 | 4.0 | 5.4 |
| Total | Nuclear | | 29.6 | 29.9 | 35.7 | 1022 | 1025 | 1025 | 1052 | 1055 | 1061 |
| | Solar | | 11.7 | 12.0 | 17.8 | 2.9 | 3.2 | 6.2 | 14.6 | 15.2 | 24.0 |
| | Wind | | 3.3 | 3.6 | 9.4 | 3.4 | 3.8 | 6.7 | 6.7 | 7.4 | 16.2 |

**Table A3. Minimal, Efficient, and Unlimited case estimates for electrolysis water consumption, additional withdrawals, and total withdrawals. Data bars show the magnitude of results for all values except nuclear electricity withdrawals.**

A. Reverse osmosis (RO) recovery rates assumed to be 85%, 78%, and 75% for Minimal, Efficient, and Unlimited, respectively (Simoes et al. 2021; Simon 2010, EPRI 2025, Lin et al., 2025). RO output water is equal to total withdrawals for electrolysis reaction. Actual RO recovery rates are highly dependent upon the source water quality and type of RO system. Polishing (e.g., ion exchange) is assumed to require no water.

B. Consumption values are based on stoichiometry (8.93 kg or 2.36 gal water per 1 kg hydrogen).

C. For each kg of hydrogen produced, approximately 0.074 gal of water is carried out of the stack in the oxygen and hydrogen gas streams, assuming a 30 bar system. Water in the oxygen stream is not recovered (to avoid additional condenser costs) and 0.044 gal per kg $H_2$ are recovered from the hydrogen stream. Losses to the atmosphere (i.e., consumption) are therefore 0.03 gal $H_2O$ per kg $H_2$ and 0.01 gal $H_2O$ per kg $H_2$ are recovered and returned to the stack, indicated as negative total withdrawals in the table. Some potential hydrogen losses, and therefore input electricity and water requirements, are avoided under the assumption that the hydrogen product does not require desiccant drying (which results in purged hydrogen). Moreover, it is assumed that some portion of recirculated reactor water is returned to the ion exchange unit (or similar unit), located downstream of the RO unit, to remove any reactor impurities (cf. Simoes et al. 2021), thereby avoiding the need for any additional withdrawals for reactor cleaning. These assumptions would vary based on system design and operating pressure.

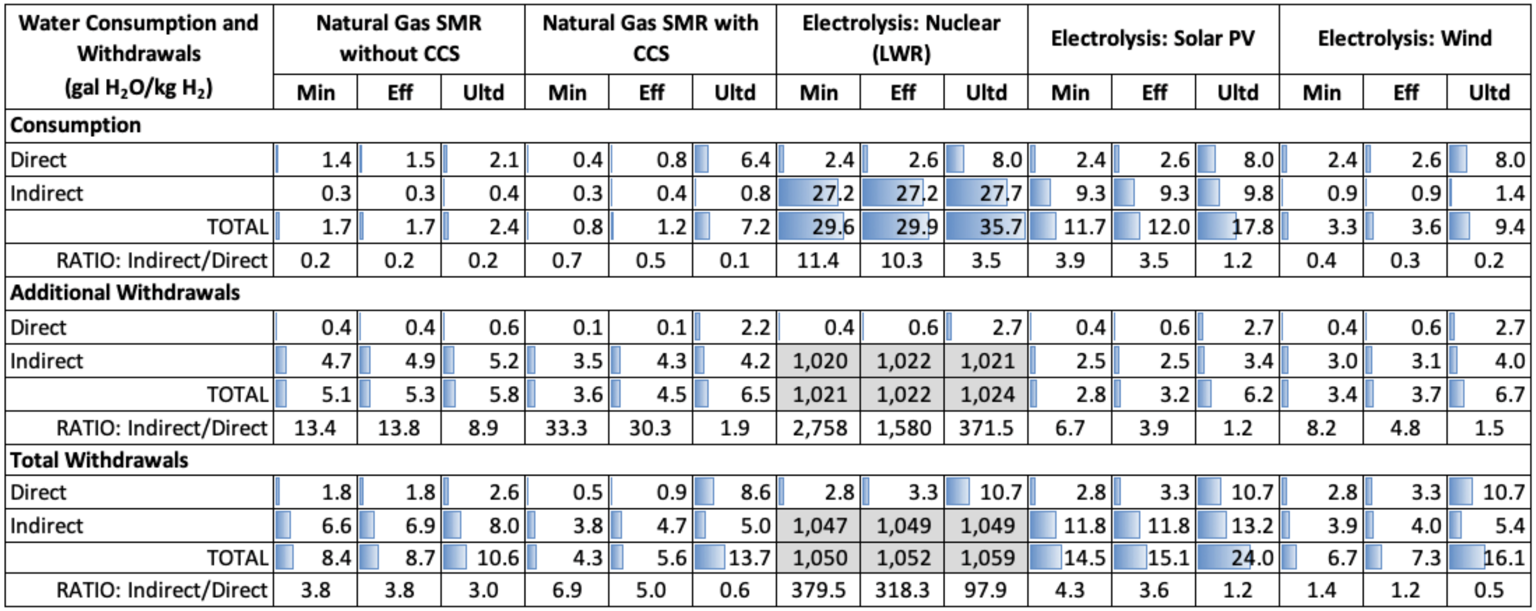
D. Minimal case assumes dry cooling with no direct water use. Efficient case assumes adiabatic cooling and the Unlimited case relies on a conventional cooling tower. Cooling details are provided in Appendix B. Additional withdrawals are due to input cooling water treatment with a 90% recovery rate.

E. Minimal case assumes dry cooling and the Efficient case has no blowdown or drift. Unlimited case blowdown and drift estimates are based on theoretical equations from Perry's Handbook (Green & Southward 2019). See details for cooling tower losses (Unlimited case only) in Appendix B.

F. Water supply losses include those in the supply of municipal water to the production facility, as well as losses during use and water management at the facility. See Table A5 for details from Simoes et al. (2021) and compare with EPA (2024).

G. Based on water consumption results from the 2024 R&D GREET2 Model for PEM electrolysis, including manufacturing and materials. Withdrawals are assumed to be proportional to the ratio of withdrawals to consumption for Solar PV (see Table A6).

H. Includes water use in electricity generation, as well as feedstock supply (nuclear only), and materials and manufacturing for generation equipment. Consumption values are from GREET and withdrawal values from EPRI 2012 (cf. Meldrum 2013). See detailed assumptions in Tables A6 and A7. Cooling electricity requirements are based on Aspen process modeling of heat removal from the electrolysis unit and BOP (hydrogen condensing and compression). Simulations were run for hourly operation in distinct climates. Details are provided in Appendix B.



| Water Consumption and Withdrawals (gal $H_2O$/kg $H_2$) | Natural Gas SMR without CCS | | | Natural Gas SMR with CCS | | | Electrolysis: Nuclear (LWR) | | | Electrolysis: Solar PV | | | Electrolysis: Wind | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Eff | Ultd | Min | Eff | Ultd | Min | Eff | Ultd | Min | Eff | Ultd | Min | Eff | Ultd |
| **Consumption** | | | | | | | | | | | | | | | |
| Direct | 1.4 | 1.5 | 2.1 | 0.4 | 0.8 | 6.4 | 2.4 | 2.6 | 8.0 | 2.4 | 2.6 | 8.0 | 2.4 | 2.6 | 8.0 |
| Indirect | 0.3 | 0.3 | 0.4 | 0.3 | 0.4 | 0.8 | 27.2 | 27.2 | 27.7 | 9.3 | 9.3 | 9.8 | 0.9 | 0.9 | 1.4 |
| TOTAL | 1.7 | 1.7 | 2.4 | 0.8 | 1.2 | 7.2 | 29.6 | 29.9 | 35.7 | 11.7 | 12.0 | 17.8 | 3.3 | 3.6 | 9.4 |
| RATIO: Indirect/Direct | 0.2 | 0.2 | 0.2 | 0.7 | 0.5 | 0.1 | 11.4 | 10.3 | 3.5 | 3.9 | 3.5 | 1.2 | 0.4 | 0.3 | 0.2 |
| **Additional Withdrawals** | | | | | | | | | | | | | | | |
| Direct | 0.4 | 0.4 | 0.6 | 0.1 | 0.1 | 2.2 | 0.4 | 0.6 | 2.7 | 0.4 | 0.6 | 2.7 | 0.4 | 0.6 | 2.7 |
| Indirect | 4.7 | 4.9 | 5.2 | 3.5 | 4.3 | 4.2 | 1,020 | 1,022 | 1,021 | 2.5 | 2.5 | 3.4 | 3.0 | 3.1 | 4.0 |
| TOTAL | 5.1 | 5.3 | 5.8 | 3.6 | 4.5 | 6.5 | 1,021 | 1,022 | 1,024 | 2.8 | 3.2 | 6.2 | 3.4 | 3.7 | 6.7 |
| RATIO: Indirect/Direct | 13.4 | 13.8 | 8.9 | 33.3 | 30.3 | 1.9 | 2,758 | 1,580 | 371.5 | 6.7 | 3.9 | 1.2 | 8.2 | 4.8 | 1.5 |
| **Total Withdrawals** | | | | | | | | | | | | | | | |
| Direct | 1.8 | 1.8 | 2.6 | 0.5 | 0.9 | 8.6 | 2.8 | 3.3 | 10.7 | 2.8 | 3.3 | 10.7 | 2.8 | 3.3 | 10.7 |
| Indirect | 6.6 | 6.9 | 8.0 | 3.8 | 4.7 | 5.0 | 1,047 | 1,049 | 1,049 | 11.8 | 11.8 | 13.2 | 3.9 | 4.0 | 5.4 |
| TOTAL | 8.4 | 8.7 | 10.6 | 4.3 | 5.6 | 13.7 | 1,050 | 1,052 | 1,059 | 14.5 | 15.1 | 24.0 | 6.7 | 7.3 | 16.1 |
| RATIO: Indirect/Direct | 3.8 | 3.8 | 3.0 | 6.9 | 5.0 | 0.6 | 379.5 | 318.3 | 97.9 | 4.3 | 3.6 | 1.2 | 1.4 | 1.2 | 0.5 |

**Table A4. Direct and indirect consumption, additional withdrawals, and total withdrawals for all production types, and for Minimal, Efficient, and Unlimited cases. Note that the size of the data bars depicts magnitude for all categories except light-water nuclear power indirect withdrawals. The ratios of indirect to direct water use show the degree to which water use is direct vs. indirect (upstream vs. onsite).**

| Water Supply to Electrolysis & SMR | Consumption (italics = Unlimited) | | Additional Withdrawals (italics = Unlimited) | | Total Withdrawals (italics = Unlimited) | |
|---|---|---|---|---|---|---|
| Abstraction/collection | 0.0% | *0.0%* | 5.0% | *5.0%* | 5.0% | *5.0%* |
| Water transport | 2.5% | *5.0%* | 2.5% | *5.0%* | 5.0% | *10.0%* |
| Facility and shortage risks | 1.0% | *1.0%* | 1.0% | *1.0%* | 2.0% | *2.0%* |
| Total | 3.5% | *6.0%* | 8.5% | *11.0%* | 12.0% | *17.0%* |

**Table A5. Water supply losses by delivery phase. Facility and shortage risk losses assumed to be minimal. (derived from Simoes at al., 2021).**

| Generation Type | 2024 Grid Mix | Consumption Gal/MWh | Consumption Source | Withdrawals Gal/MWh | Withdrawals Source |
|---|---|---|---|---|---|
| Coal | 20.4% | 463 | GREET 2024 | 11,144 | EPRI 2012 |
| NG CT | 1.8% | 266 | GREET 2024* | 11,581 | EPRI 2012* |
| NG CCT | 28.9% | 194 | GREET 2024 | 8,470 | EPRI 2012 |
| Nuclear | 19.0% | 467 | GREET 2024 | 18,179 | EPRI 2012 |
| Hydropower | 7.0% | 4,639 | GREET 2024 | 4,639 | eq. consumption |
| Geothermal | 0.4% | 1,531 | GREET 2024 | 1,531 | eq. consumption |
| Biomass | 0.5% | 431 | GREET 2024 | 38,708 | EPRI 2012 |
| Solar | 9.0% | 156 | GREET 2024** | 195 | EPRI 2012 |
| Wind | 12.8% | 10 | GREET 2024 | 59 | EPRI 2012 |
| Battery Storage | 0.2% | 72 | GREET 2024 | 72 | eq. consumption |
| Weighted Ave | | 594 | | 8,937 | |

**Table A6. Assumptions for water withdrawals and consumption for the 2024 average grid mix.**

NOTES:
- Nuclear reflects light-water nuclear reactors. Advanced reactor designs are not represented.
- For hydropower, geothermal, and battery storage, withdrawal is equivalent to consumption.
- These mean values from EPRI 2012 result in an average 2024 grid mix withdrawal rate that is relatively consistent with the historical trend towards ~9,000 gal/MWh reported by EIA (2023).
- For solar PV, materials and manufacturing are from GREET, while the GREET Water Consumption Factor has been adjusted to represent only flat panel PV system operation (based on Meldrum 2013, and discussed in Table 20 from Lampert et al, 2015). See Table A7.
- See Table A7 for breakdown of nuclear and wind.
- Each calculation includes the GREET electricity transmission and distribution loss of 4.9%.

| Water consumption by type | Nuclear (LWR) (gal/MWh) | Nuclear (LWR) (%) | Solar PV (gal/MWh) | Solar PV (%) | Wind (gal/MWh) | Wind (%) |
|---|---|---|---|---|---|---|
| Materials and Manufacturing | 0.2 | 0.04% | 150.0 | 96.0% | 9.1 | 89.6% |
| Fuel supply (Uranium only) | 43.8 | 9% | 0 | 0% | 0 | 0% |
| Operation | 422.6 | 91% | 6.3 | 4.0% | 1.1 | 10.4% |
| Total | 466.6 | 100% | 156.3 | 100% | 10.1 | 100% |

**Table A7. Breakdown of water consumption by electrolysis electricity source (see GREET2, and notes in Table A6).**

| Summary Results | [gal H2O per kg H2] | | | [liters H2O per kg H2] | | |
|---|---|---|---|---|---|---|
| | Minimal | Efficient | Unlimited | Minimal | Efficient | Unlimited |
| Direct water consumption | | | | | | |
| Conventional SMR | 1.4 | 1.5 | 2.1 | 5.3 | 5.5 | 7.8 |
| SMR with CCS | 0.4 | 0.8 | 6.4 | 1.7 | 3.0 | 24.2 |
| Nuclear electrolysis | 2.4 | 2.6 | 8.0 | 9.0 | 10.0 | 30.1 |
| Solar PV electrolysis | 2.4 | 2.6 | 8.0 | 9.0 | 10.0 | 30.1 |
| Wind electrolysis | 2.4 | 2.6 | 8.0 | 9.0 | 10.0 | 30.1 |
| Indirect water | | | | | | |
| Conventional SMR | 0.3 | 0.3 | 0.4 | 1.0 | 1.0 | 1.3 |
| SMR with CCS | 0.3 | 0.4 | 0.8 | 1.2 | 1.5 | 3.0 |
| Nuclear electrolysis | 27.2 | 27.2 | 27.7 | 102.8 | 103.1 | 104.9 |
| Solar PV electrolysis | 9.3 | 9.3 | 9.8 | 35.2 | 35.3 | 37.3 |
| Wind electrolysis | 0.9 | 0.9 | 1.4 | 3.3 | 3.4 | 5.4 |
| Total water consumption | | | | | | |
| Conventional SMR | 1.7 | 1.7 | 2.4 | 6.3 | 6.5 | 9.1 |
| SMR with CCS | 0.8 | 1.2 | 7.2 | 2.8 | 4.5 | 27.2 |
| Nuclear electrolysis | 29.6 | 29.9 | 35.7 | 111.9 | 113.1 | 135.0 |
| Solar PV electrolysis | 11.7 | 12.0 | 17.8 | 44.2 | 45.3 | 67.4 |
| Wind electrolysis | 3.3 | 3.6 | 9.4 | 12.4 | 13.4 | 35.5 |
| Direct water withdrawals | | | | | | |
| Conventional SMR | 1.8 | 1.8 | 2.6 | 6.7 | 6.8 | 10.0 |
| SMR with CCS | 0.5 | 0.9 | 8.6 | 2.1 | 3.5 | 32.7 |
| Nuclear electrolysis | 2.8 | 3.3 | 10.7 | 10.4 | 12.5 | 40.5 |
| Solar PV electrolysis | 2.8 | 3.3 | 10.7 | 10.4 | 12.5 | 40.5 |
| Wind electrolysis | 2.8 | 3.3 | 10.7 | 10.4 | 12.5 | 40.5 |
| Indirect water | | | | | | |
| Conventional SMR | 6.6 | 6.9 | 8.0 | 25.2 | 26.1 | 30.2 |
| SMR with CCS | 3.8 | 4.7 | 5.0 | 14.3 | 17.8 | 19.1 |
| Nuclear electrolysis | 1,047 | 1,049 | 1,049 | 3,965 | 3,970 | 3,970 |
| Solar PV electrolysis | 11.8 | 11.8 | 13.2 | 44.5 | 44.8 | 50.1 |
| Wind electrolysis | 3.9 | 4.0 | 5.4 | 14.9 | 15.1 | 20.5 |
| Total water withdrawals | | | | | | |
| Conventional SMR | 8.4 | 8.7 | 10.6 | 31.9 | 32.9 | 40.2 |
| SMR with CCS | 4.3 | 5.6 | 13.7 | 16.3 | 21.3 | 51.7 |
| Nuclear electrolysis | 1,050 | 1,052 | 1,059 | 3,975 | 3,982 | 4,010 |
| Solar PV electrolysis | 14.5 | 15.1 | 24.0 | 55.0 | 57.3 | 90.7 |
| Wind electrolysis | 6.7 | 7.3 | 16.1 | 25.3 | 27.6 | 61.0 |

**Table A8. Summary results in gallons and liters of water per kg hydrogen produced. Additional withdrawals (not shown) are equal to withdrawals minus consumption.**

## Appendix B. Calculation details

**Table B1. Additional equations and assumptions for electrolysis.**

| **Category** | | | **Estimated Value** | **Calculation** | **Notes** |
|---|---|---|---|---|---|
| Electrolysis | Direct | Consumption | Electrolysis Reaction | $\frac{\frac{1\ L\ water}{1\ kg\ water}\cdot\frac{(2\cdot MW_{Hydrogen}+MW_{Oxygen})}{2\cdot MW_{Hydrogen}}}{3.785\ L/gal}$<br>$MW_{Hydrogen}$ = 1.00784 u<br>$MW_{Oxygen}$ = 15.999 u | MW = molecular weight |
| | | | Vapor losses and condensate | 0.03 gal $H_2O$/kg $H_2$ (Aspen simulation result) | |
| | | | Cooling water use | **Hybrid Case:** 0.26 gal $H_2O$/kg $H_2$ (Aspen simulation result) | |
| | | | | **Unlimited Case:** $WC_{Cool} = Q_{Th\_Total}\cdot W_{Evap}$<br>$WC_{Cool}$ = Water consumption for cooling (gal $H_2O$/kg $H_2$)<br>$Q_{Th\_Total}$ = Total heat removed through cooling (kWh-th/kg $H_2$)<br>$W_{Evap}$ = Water evaporated through cooling (gal $H_2O$/kWh-th)<br>$W_{Evap} = \frac{(1.8\ gal/ton\cdot hour)\cdot(3412\ Btu/kWh)}{15000\ btu/ton\cdot hour}$<br>$Q_{Th\_Total} = Q_{Th\_Elzr} + Q_{Th\_H2Comp} + Q_{Th\_H2Cond}$<br>$Q_{Th\_Elzr}$ = Thermal load from electrolyzer<br>$Q_{Th\_H2Comp}$ = Thermal load from H2 compressors<br>$Q_{Th\_H2Cond}$ = Thermal load from H2 condensers | Source for $W_{Evap}$: Perry's Handbook |

**Table B1. Additional equations and assumptions for electrolysis (continued).**

| Category | | | Estimated Value | Calculation | Notes |
|---|---|---|---|---|---|
| Electrolysis | Direct | Consumption | Cooling Water use | **Unlimited Case (cont.):**<br>$Q_{Th\_Elzr} = E_{Stack} - E_{H2} - E_{Other}$<br>$E_{Stack}$ = Energy input to stack<br>$E_{H2}$ = Hydrogen energy output<br>$E_{Other}$ = Other energy output<br>$E_{Stack} = 53.3\ kWh/kg$ (Hubert et al. 2022)<br>$E_{H2} = 39.4\ kWh/kg\ (HHV\ H2)$<br>$E_{Other} = 1.39\ kWh/kg\ (Aspen\ results)$<br>$Q_{Th_{H2Comp}} = 0.9\ kWh/kg\ (Aspen\ results)$<br>$Q_{Th\_H2Cond} = 0.2\ kWh/kg\ (Aspen\ results)$ | |
| | | Additional Withdrawals | Purification of electrolysis water (via RO) | $(TW_{ER} + TW_{VLC}) \cdot \left(\frac{1}{(\eta_{RO} - 1)}\right)$<br>$TW_{ER}$ = Total withdrawals electrolysis reaction<br>$TW_{VLC}$ = Total withdrawals vapor losses and condensate<br>$\eta_{RO}$ = Reverse osmosis recovery rate<br>$\eta_{RO} = (85\%, 78\%, 75\%)$ (Minimal, Efficient, Unlimited) | |
| | | | Vapor losses and condensate | -0.04 gal $H_2O$/kg $H_2$ (Aspen simulation result) | Recovery is larger than losses, resulting in negative withdrawals. |
| | | | Cooling water treatment | $AW_{Cool} = WC_{Cool}\big(10\%/(1 - 10\%)\big)$ | |

**Table B1. Additional equations and assumptions for electrolysis (continued).**

| Category | | | Estimated Value | Calculation | Notes |
|---|---|---|---|---|---|
| Electrolysis | Direct | Additional Withdrawals | Blowdown and drift | $W_{C\text{-}H2} = Q_{Thermal\_Total} / (k_{HCW} * (T_2 - T_1))$<br>$W_{C\text{-}H2}$ = Water circulation rate (gal $H_2O$/kg $H_2$)<br>$Q_{Thermal}$ = Heat that must be rejected from the system via cooling (kJ thermal per kg H2)<br>$k_{HCW}$ = Heat capacity of water (4.186 kJ/liter-K)<br>$T_2 - T_1$ = Difference between water outlet and inlet temperature (assumed to be 5ºC)<br>$W_{DRIFT\text{-}H2} = f_{DRIFT} * W_{C\text{-}H2}$<br>$W_{DRIFT\text{-}H2}$ = Drift loss (gal $H_2O$/kg $H_2$)<br>$f_{DRIFT} = 0.02\%$<br>$W_{BLOWDOWN\text{-}H2} = (W_{EVAP\text{-}H2} - (N_{Cycles} - 1) * W_{DRIFT\text{-}H2}) / (N_{Cycles} - 1)$<br>$N_{Cycles}$ = 5 cycles | Drift loss can be calculated as a percent of the water circulation rate through the electrolysis unit.<br>See Perry's Handbook. |

**Table B1. Additional equations and assumptions for electrolysis (continued).**

| Category | | | Estimated Value | Calculation | Notes |
|---|---|---|---|---|---|
| Electrolysis | Indirect Use | Consumption | Water Supply Losses | $$WC_{WSL} = TW_{Direct} \cdot WSL_{Consumption}$$<br>$WC_{WSL}$ = Water consumption water supply losses<br>$TW_{Direct}$ = Total Withdrawals, Direct<br>$WSL_{Consumption}$ = 3.5% (Minimal & Efficient), 6% (Unlimited) | See Simoes et al. 2021 and Table A5. |
| | | | Electrolysis Manufacturing | 0.2 gal $H_2O$/kg $H_2$ | GREET2, all cases. |
| | | | Electricity for Electrolysis | $$WC_{Elec} = E_{Electricity,input} \cdot WCI_{Electricity,n}$$<br>$WC_{Elec}$ = Water consumption, electricity for electrolysis<br>$E_{Electricity,input}$ = all input electricity (stack, BOP, cooling)<br>$WCI_{Electricity,n}$ = Water consumption intensity, source n | See Table A6 for WCI values by source n. |
| | | Additional Withdrawals | Water Supply Losses | $$AW_{WSL} = TW_{Direct} \cdot WSL_{AW}$$<br>$AW_{WSL}$ = Additional withdrawals, water supply losses<br>$TW_{Direct}$ = Total Withdrawals, Direct<br>$WSL_{AW}$ = See Table A5. | See Simoes et al. 2021 and Table A5. |
| | | | Electrolysis Manufacturing | 0.05 gal $H_2O$/kg $H_2$ | GREET2, all cases. |

**Table B1. Additional equations and assumptions for electrolysis (continued).**

| Category | | | Estimated Value | Calculation | Notes |
|---|---|---|---|---|---|
| Electrolysis | Indirect Use | Additional Withdrawals | Electricity for Electrolysis | $WC_{Elec} = E_{Electricity,input} \cdot WCI_{Electricity,n}$<br>$WC_{Elec}$ = Water consumption, electricity for electrolysis<br>$E_{Electricity,input}$ = all input electricity (stack, BOP, cooling)<br>$WCI_{Electricity,n}$ = Water consumption intensity, source n | See Table A6 for WCI values by source. |

**Table B2. Additional equations and assumptions for SMR with and without CCS.**

| Category | | | Estimated Value | Calculation | Notes |
|---|---|---|---|---|---|
| SMR with and without CCS | Direct | Consumption | SMR Process | • SMR woCCS: Includes *SMR Steam* and *Syngas Condensate* (recovered) from Exhibit 3-10 (Lewis 2022).<br>• SMR wCCS: Includes *SMR Steam* and *Syngas Condensate* (recovered) from Exhibit 3-28 (Lewis 2022). | Export steam water in Exhibit 3-10 allocated to steam end use. |
| | | | Cooling water use | • SMR woCCS: Unlimited: Includes *Cooling Tower* water from Exhibit 3-10 (Lewis 2022). Hybrid: proportional to electrolysis.<br>• SMR wCCS: Unlimited: Includes *Cooling Tower* water from Exhibit 3-28 (Lewis 2022). Hybrid: proportional to electrolysis. | |
| | | | Carbon capture and storage | • SMR wCCS: Includes *$CO_2$ Drying, $CO_2$ Capture System Makeup, and $CO_2$ Compression Recovery* water, Exhibit 3-28 (Lewis 2022). | |
| | | Additional Withdrawals | Water treatment | $(TW_{SMR}) \cdot \left(\frac{1}{(\eta_{RO} - 1)}\right)$<br>$TW_{ER}$ = Total withdrawals SMR process<br>$\eta_{RO}$ = Reverse osmosis recovery rate<br>$\eta_{RO} = (80\%)$ (All Cases) | |
| | | | Cooling | $(WC_{Cool}) \cdot \left(\frac{1}{(\eta_{TRT} - 1)}\right)$<br>$WC_{Cool}$ = Water Consumption cooling<br>$\eta_{TRT}$ = Treatment recovery rate<br>$\eta_{RO} = (90\%)$ (All Cases) | |
| | | | Blowdown and drift | Proportional to blowdown and drift per cooling tower water consumption in electrolysis. | |

**Table B2. Additional equations and assumptions for SMR with and without CCS (continued).**

| Category | | | Estimated Value | Calculation | Notes |
|---|---|---|---|---|---|
| SMR with and without CCS | Direct | Water Consumption | Natural gas supply | Consumption value from GREET for natural gas water use. | |
| | | | Water Supply Losses | $$AW_{WSL} = TW_{Direct} \cdot WSL_{AW}$$<br>$AW_{WSL}$ = Additional withdrawals, water supply losses<br>$TW_{Direct}$ = Total Withdrawals, Direct<br>$WSL_{AW}$ = See Table A5. | See Simoes et al. 2021 and Table A5. |
| | | | Electricity for cooling and auxiliaries. | Determined using average grid electricity water use (Table A6) and kWh used for cooling (proportional to electrolysis cooling water electricity per heat rejected) and auxiliaries (Lewis 2022). | |
| SMR with and without CCS | Indirect | Additional withdrawals | Natural gas supply | Withdrawal value from EPRI (2012) for natural gas use. | |
| | | | Water Supply Losses | $$AW_{WSL} = TW_{Direct} \cdot WSL_{AW}$$<br>$AW_{WSL}$ = Additional withdrawals, water supply losses<br>$TW_{Direct}$ = Total Withdrawals, Direct<br>$WSL_{AW}$ = See Table A5. | See Simoes et al. 2021 and Table A5. |
| | | | Electricity for cooling and auxiliaries. | Determined using average grid electricity water use (Table A6) and kWh used for cooling (proportional to electrolysis cooling water electricity per heat rejected) and auxiliaries (Lewis 2022). | |

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