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PRESENTATION AT DOE'S ELECTROLYZER INSTALLATION WORKSHOP

Analysis of Water Consumption and Regional Water Stress Associated with Clean Hydrogen Production

WATER

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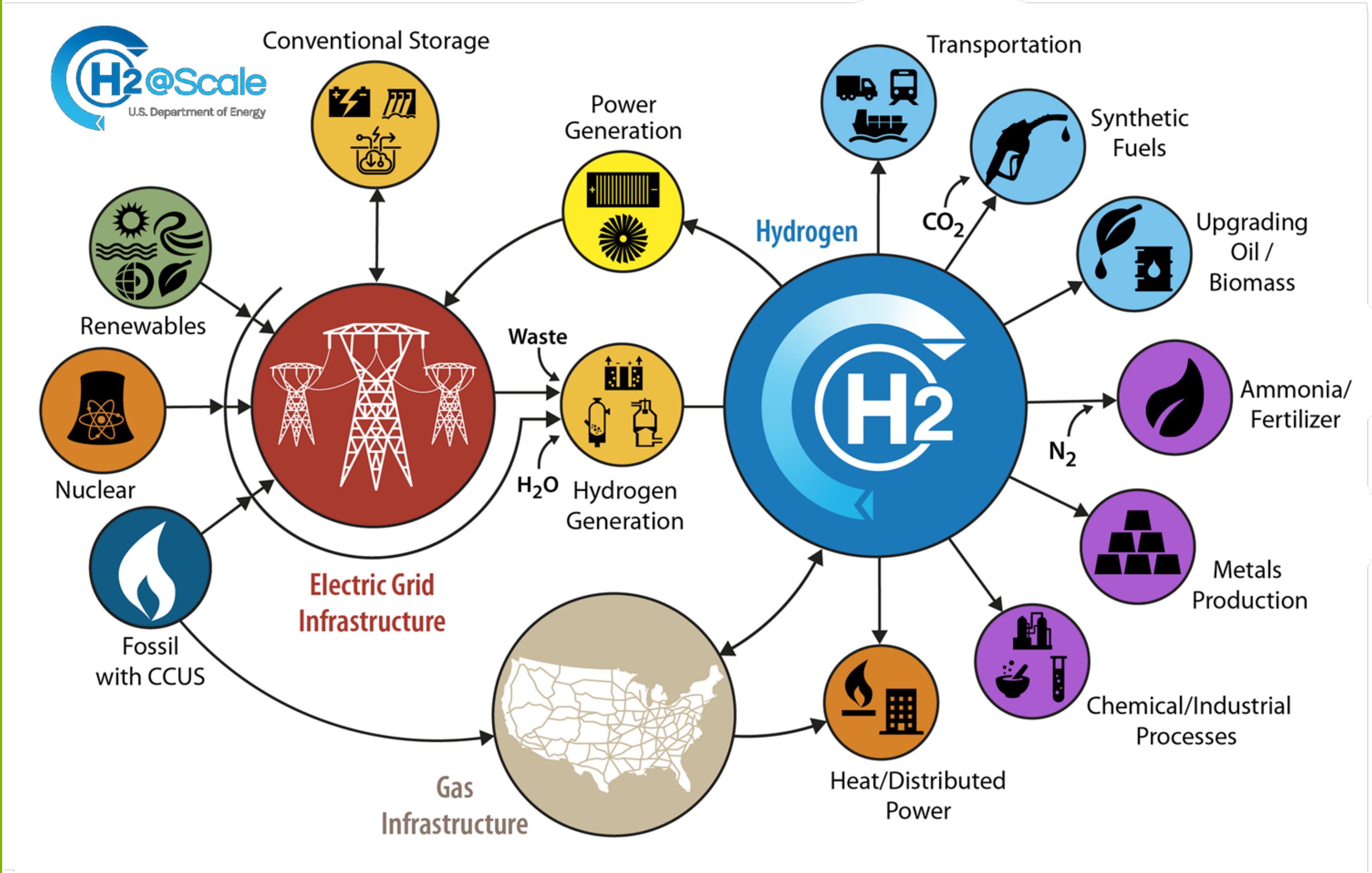
H2@Scale: a blueprint for a hydrogen economy



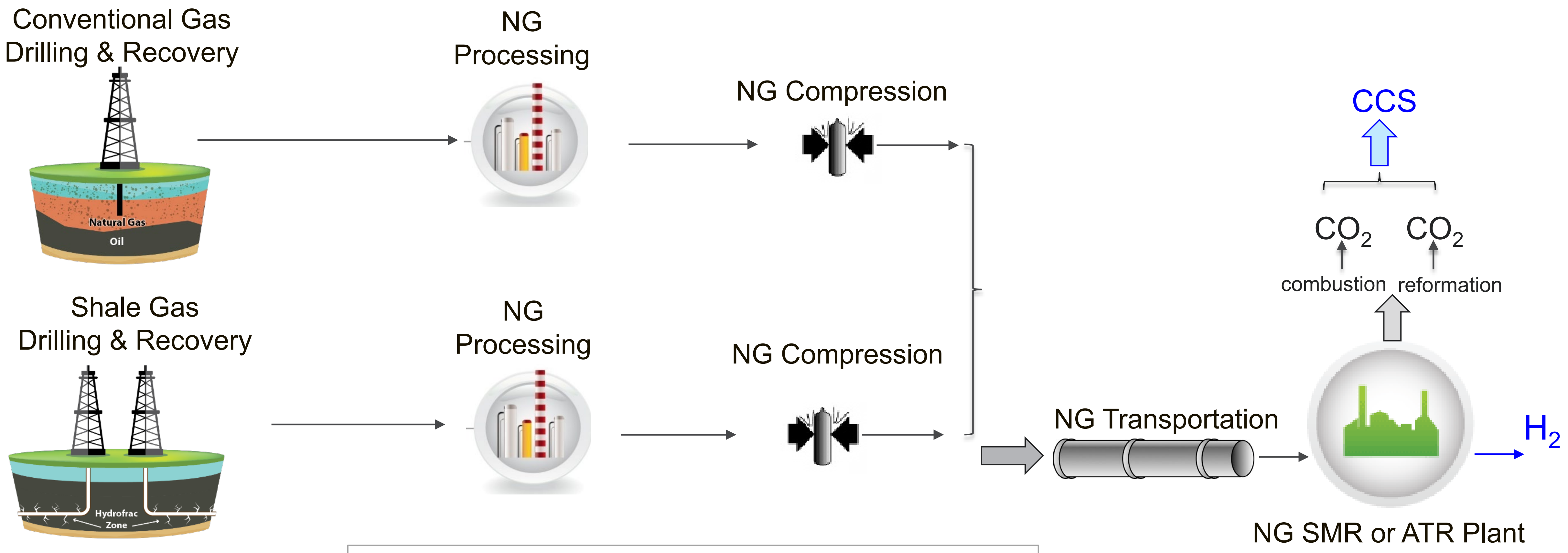
Incentives:

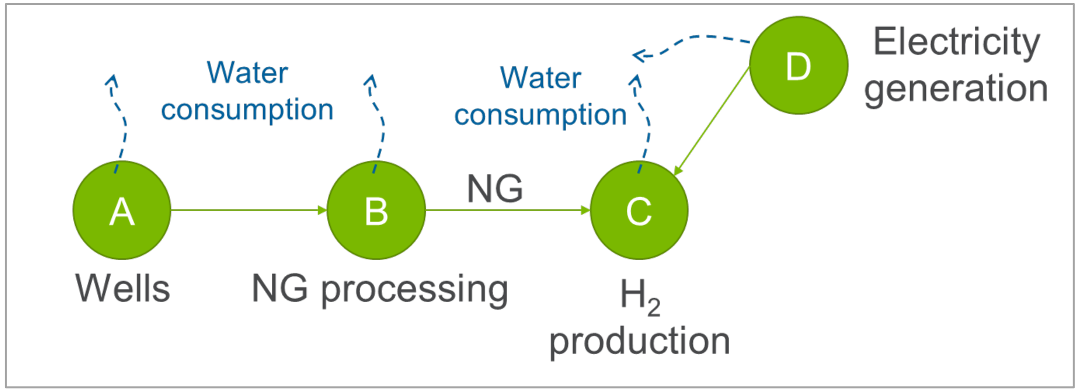
- Bipartisan Infrastructure Law (BIL)
  - ✓ \$9.5B for clean H_2 production and deployment
- Inflation Reduction Act (IRA)
  - ✓ Up to \$3/kg credit based on H_2 well-to-gate carbon intensity (CI)
  - ✓ Argonne GREET model for CI calculations

Concerns:

- Water consumption associated with large scale H2 deployment
- Regional water stress

Clean hydrogen production pathway: CH_4 reforming w/ CCS



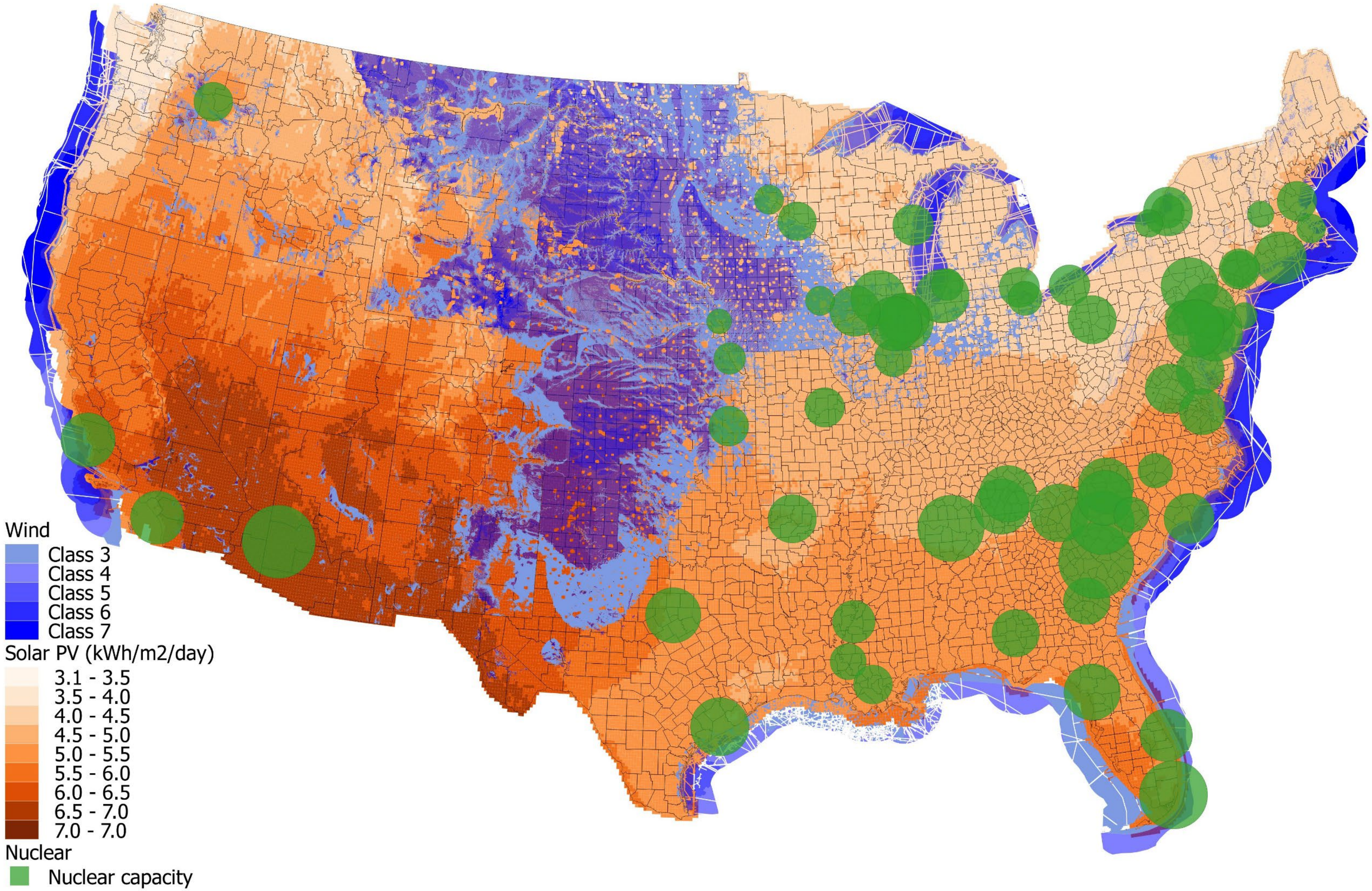


$CH_4 + H_2O\ (\text{steam}) \rightarrow CO + 3\ H_2$
$CO + H_2O\ (\text{steam}) \rightarrow CO_2 + H_2$

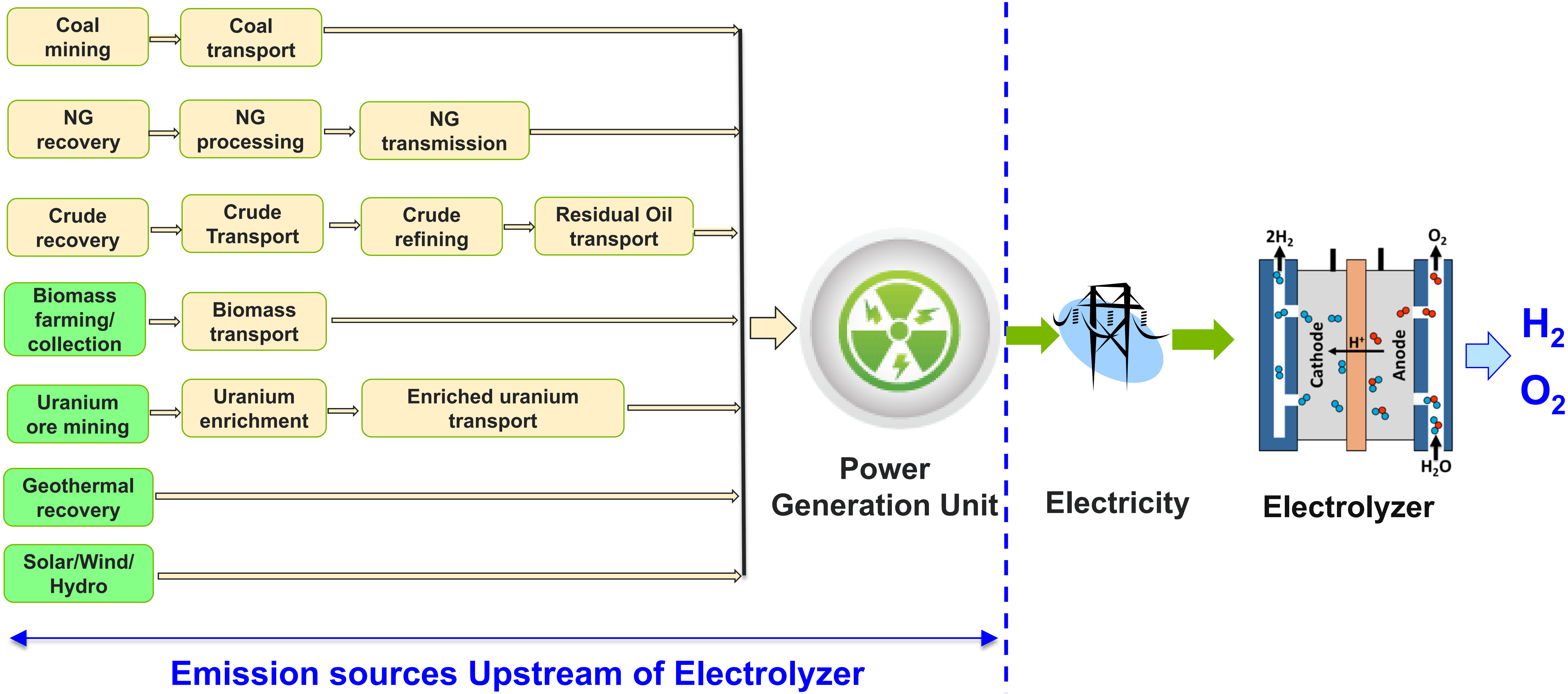
NG = natural gas
SMR = steam methane reforming
ATR = auto-thermal reforming

Available resources for clean H_2 production via water electrolysis (solar / wind / nuclear)

(Solar and wind resources from NREL)



Clean hydrogen production pathway: water electrolysis



Water consumption factor (WCF) for H_2 production (gal/kg)

	H_2 Production Technology				
	SMR			Electrolysis	
Process	Central w/o CCS	Central w/CCS	Distributed	Central	Distributed
Production Process	1.7	1.7	2.5	2.9	2.9
Cooling Loss	0.65	1.2	0	1.2	0
Total WCF [gal/kgH_2]	**2.4**	**2.9**	**2.5**	**4.1**	**2.9**

- ✓ Water consumption for H_2 production = water withdrawal – water rejection
- ✓ Average at-home water use is 80-100 gallons/person/day (USGS)

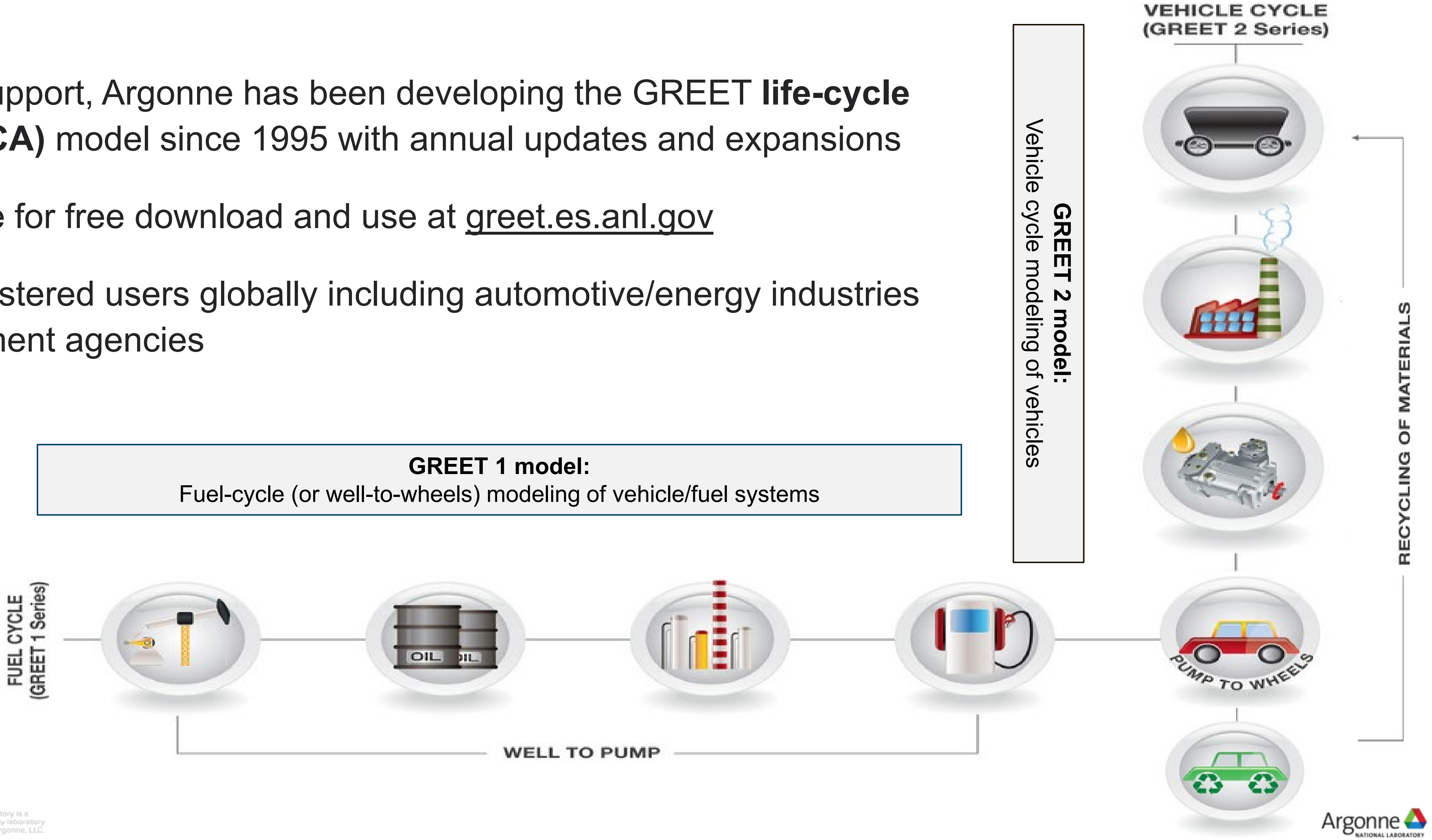
Upstream WCFs

Electricity	Wind	0.001 gal/kWh
	Solar PV	0.018 gal/kWh
	Solar CSP	0.26 gal/kWh
	Nuclear (once-through)	~0 gal/kWh
	Nuclear (recirculating)	0.40 gal/kWh
Conventional NG†	Recovery	0.25 gal/mmBtu
	Processing	1.92 gal/mmBtu
Shale gas†	Recovery	3.90 gal/mmBtu
	Processing	2.01 gal/mmBtu

† NG T&D WCF: 0.22 gal/mmBtu

The GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model for H_2 CI and water consumption evaluation

- With DOE support, Argonne has been developing the GREET **life-cycle analysis (LCA)** model since 1995 with annual updates and expansions
- It is available for free download and use at greet.es.anl.gov
- >55,000 registered users globally including automotive/energy industries and government agencies



GREET sustainability metrics include energy use, criteria air pollutants, GHG, and water consumption

Energy use

- Total energy: fossil energy and renewable energy
- Fossil energy: petroleum, natural gas, and coal
- Renewable energy: biomass, nuclear energy, hydro-power, wind power, and solar energy

Resource availability and energy security

Air pollutants

- VOC, CO, NOx, PM_{10}, $PM_{2.5}$, and SOx
- Estimated separately for total and urban (a subset of the total) emissions

Human health and environmental justice

Greenhouse gases

- CO_2, CH_4, N_2O, black carbon, and albedo
- CO_{2e} of the five (with their global warming potentials)

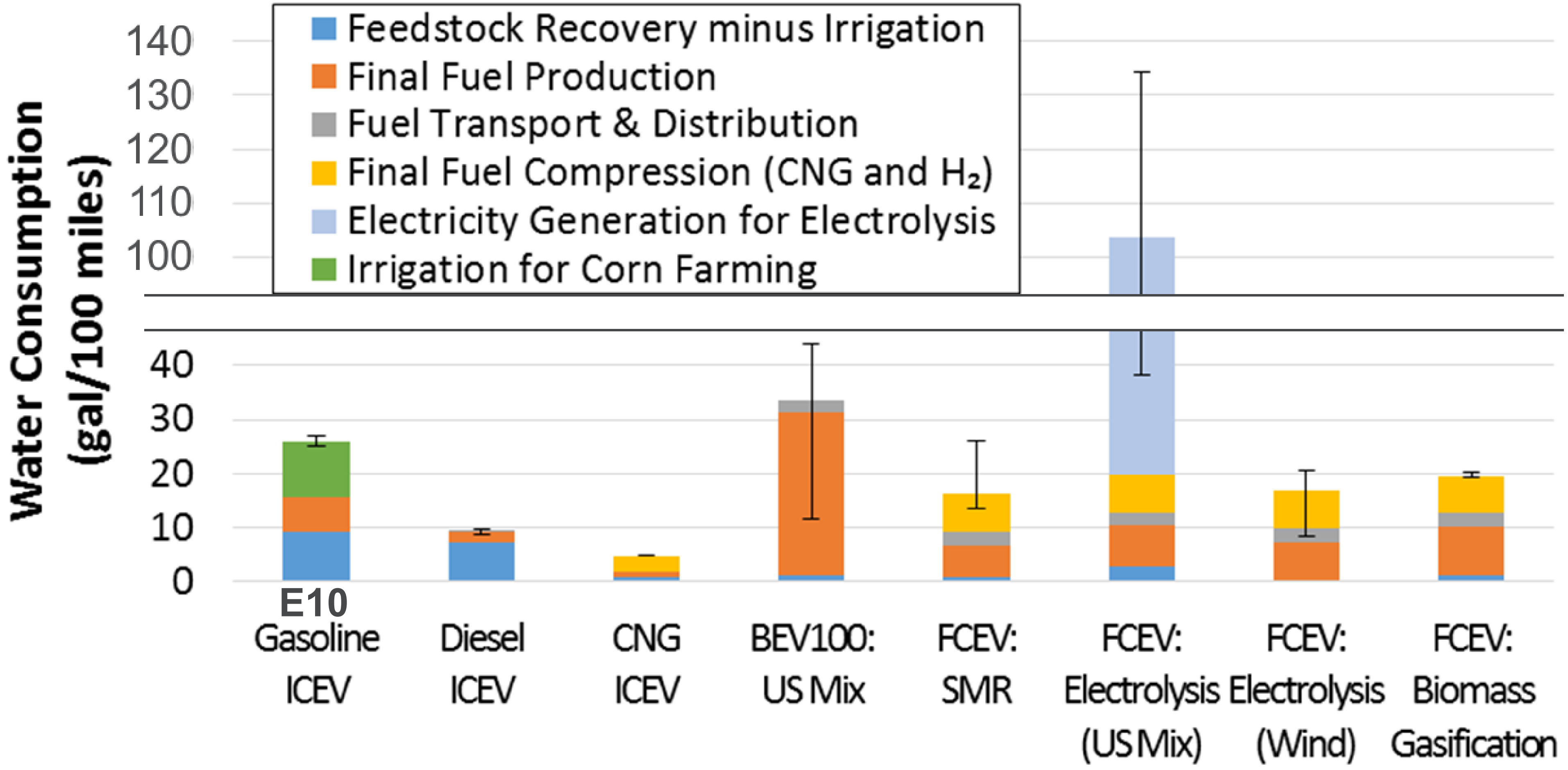
Global warming impacts

Water consumption

- Addressing water supply and demand (energy-water nexus)

Regional/seasonal water stress impacts

Life-cycle water consumption of various transportation fuels: H_2 for FCEVs is comparable with other fuels



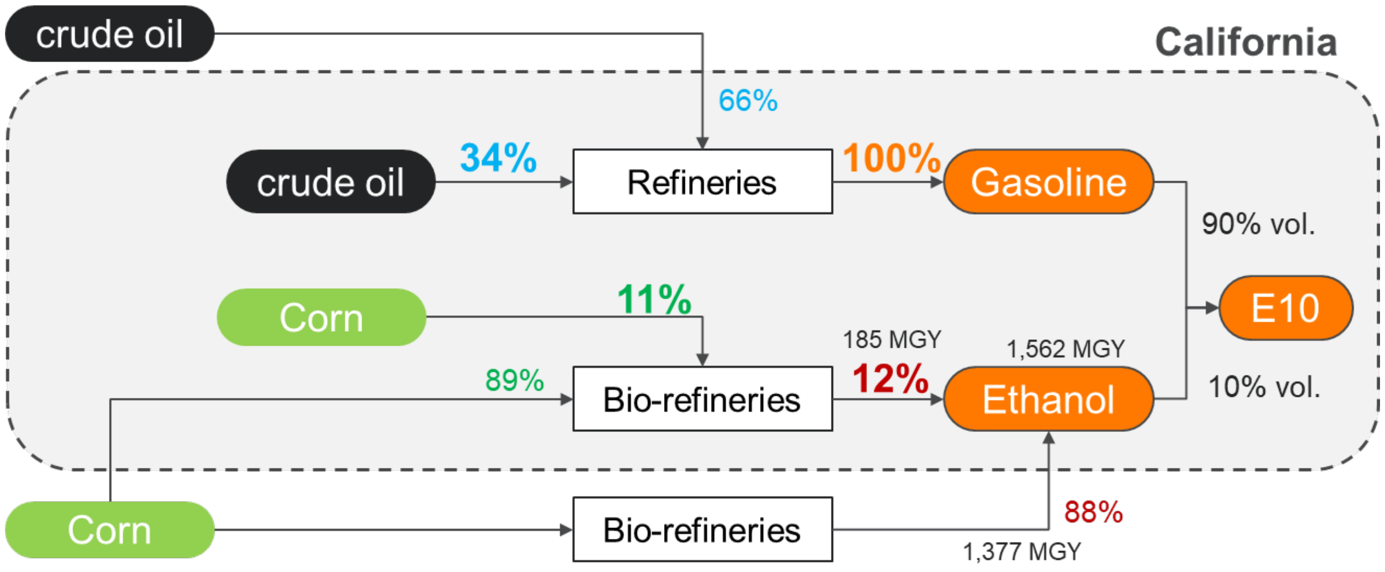
Fuel Economy: (MPPGE) 26 31 27 94 55 55 55 55

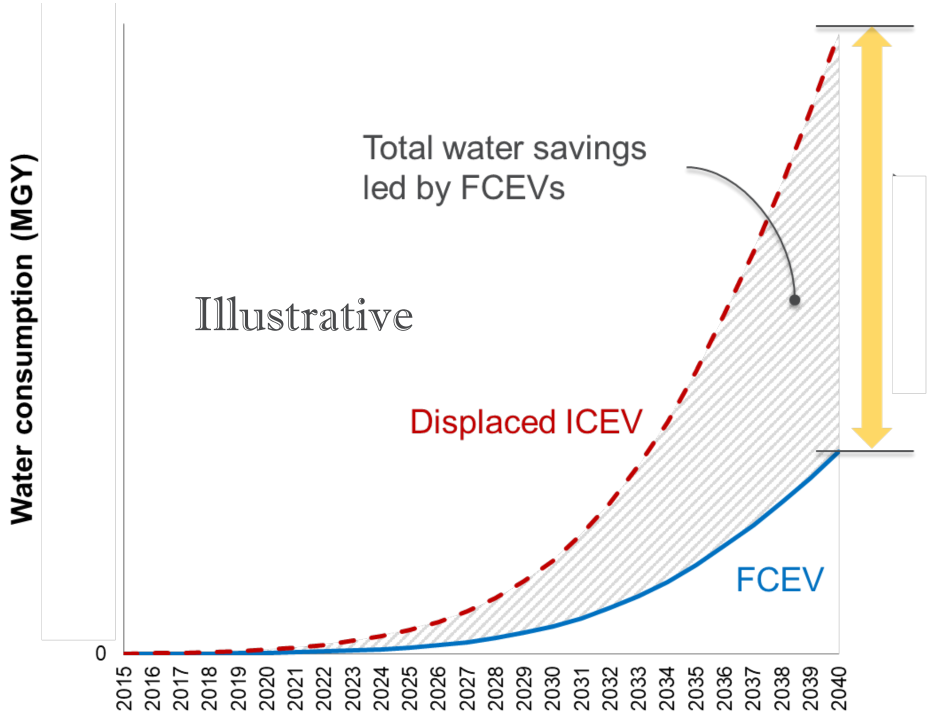
Source: https://www.hydrogen.energy.gov/pdfs/review16/sa039_elgowainy_2016_o.pdf

FCEVs displace ICEVs; there is net water saving
→ But water consumption and impacts are a regional issue

For example:

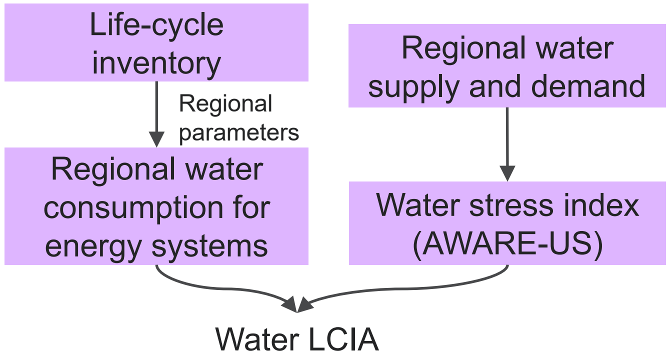
- H_2 production may be located near H_2 demand in CA, while only a small portion of E10 ethanol supply chain is in CA (e.g., ethanol coming from Midwest)



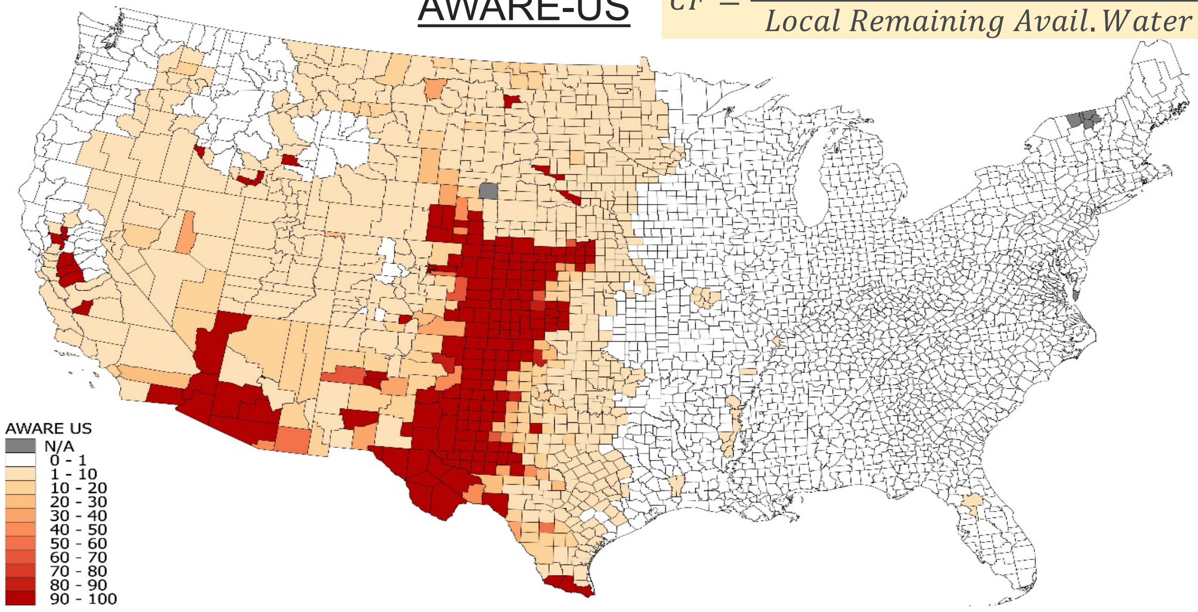


Regional water supply-demand balance is key for H_2, power generation, biofuels; Argonne AWARE-US model addresses regional/seasonal water stress impacts

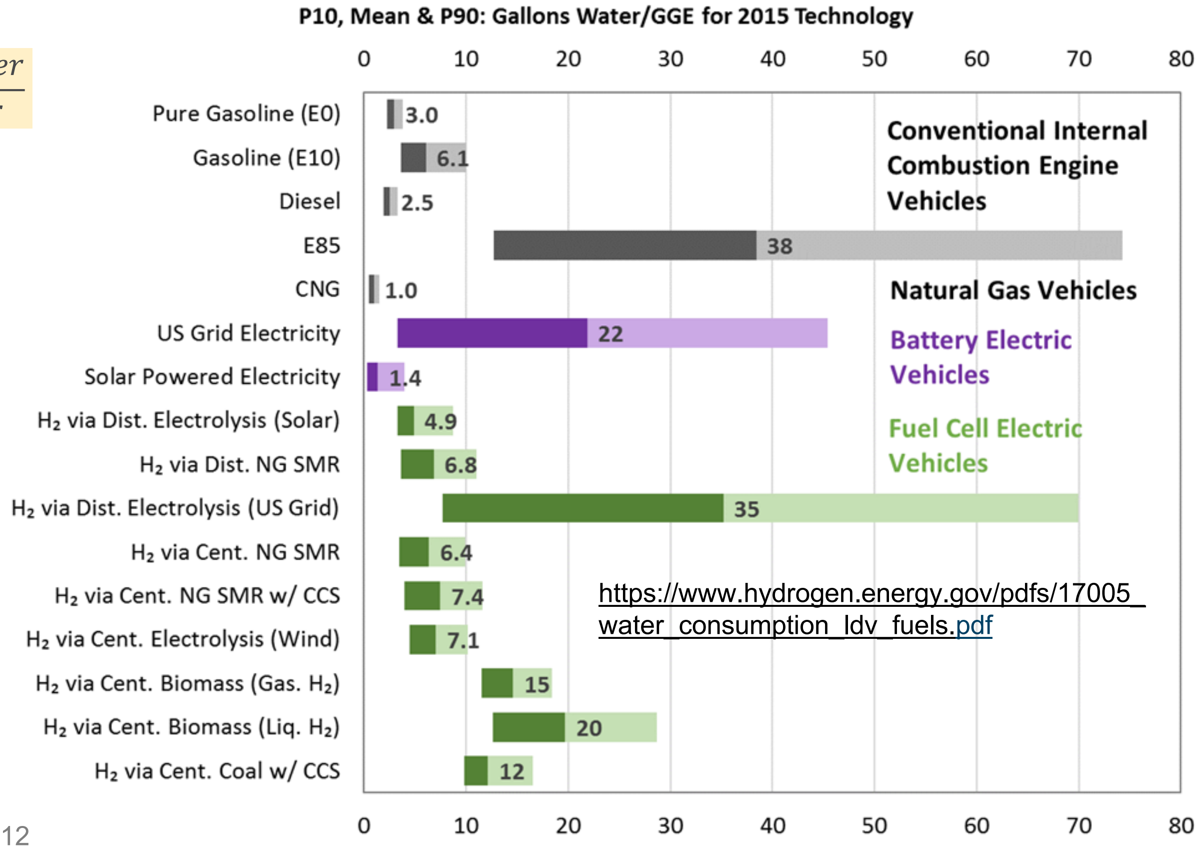
- Brings together water consumption and ambient water availability.
- Considers hydrologic flows and societal water use at county level.
- Applying to a wide range of energy supply chains.



AWARE-US $CF = \frac{Ntl\ Avg\ Remaining\ Avail. Water}{Local\ Remaining\ Avail. Water}$



https://www.sciencedirect.com/science/article/pii/S0048969718332145



https://www.hydrogen.energy.gov/pdfs/17005_water_consumption_ldv_fuels.pdf

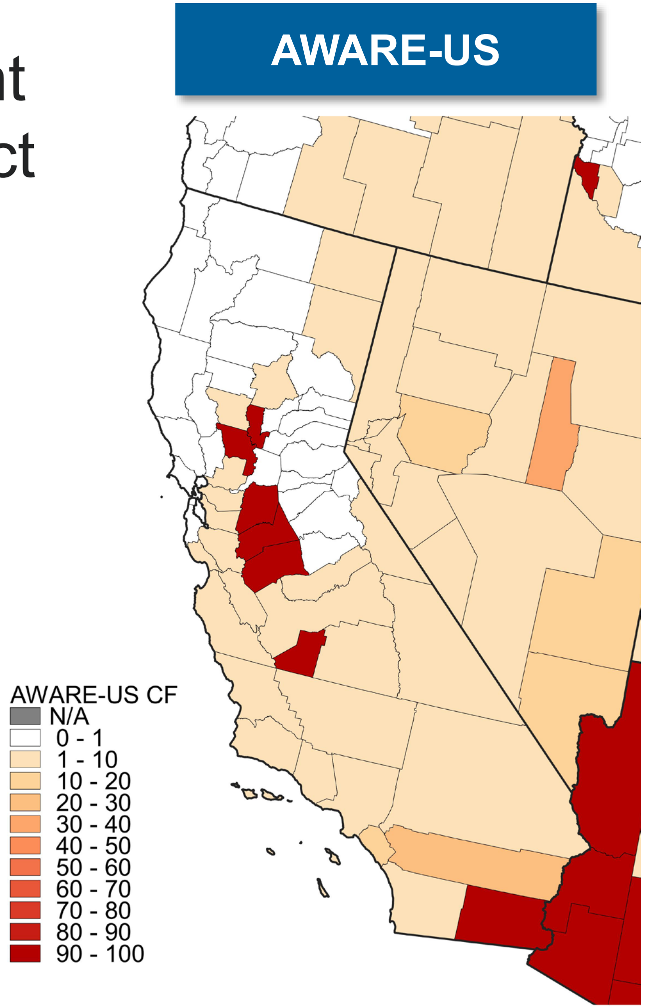
AWARE = Available Water Remaining

Water stress analysis

- Depending on freshwater availability, even the same amount of water consumption may have different water stress impact
- AWARE-US developed by ANL can be used to evaluate water scarcity footprint (WSF)
- WSF expressed in terms of 'gallon of water consumption equivalent' reflects both water consumption and freshwater availability in each region

Water scarcity footprint (m^3 $eq.$)

$$= [\text{Water consumption}]_i\ (m^3) \times [\text{AWARE CF}]_i$$

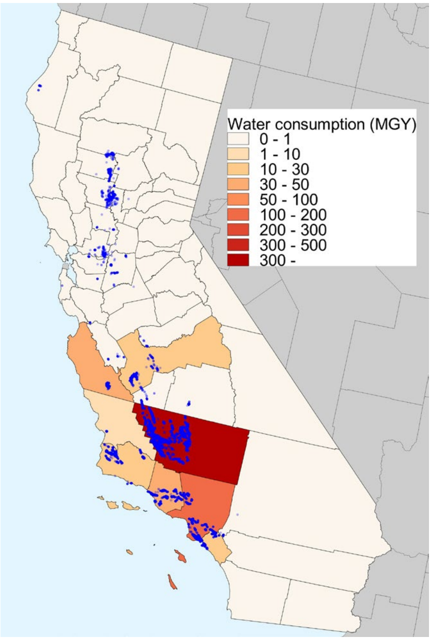


Regional water consumption for E10 gasoline in CA

- Upstream water consumption burdens for E10 production are disaggregated to the counties where water is consumed at each stage

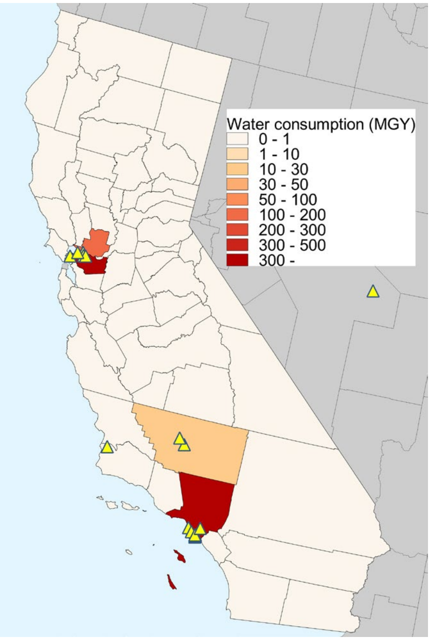
Water consumption for crude oil recovery	Water consumption for refineries	Water consumption for corn cultivation	Water consumption for bio-refineries

Active crude wells

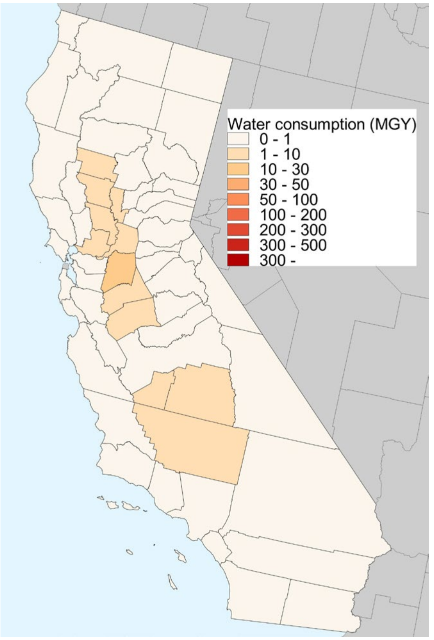


825 MGY

Refineries

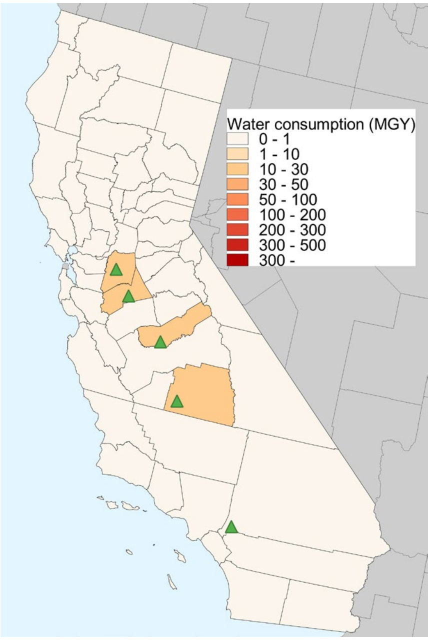


2,129 MGY



59 MGY

Bio-refineries



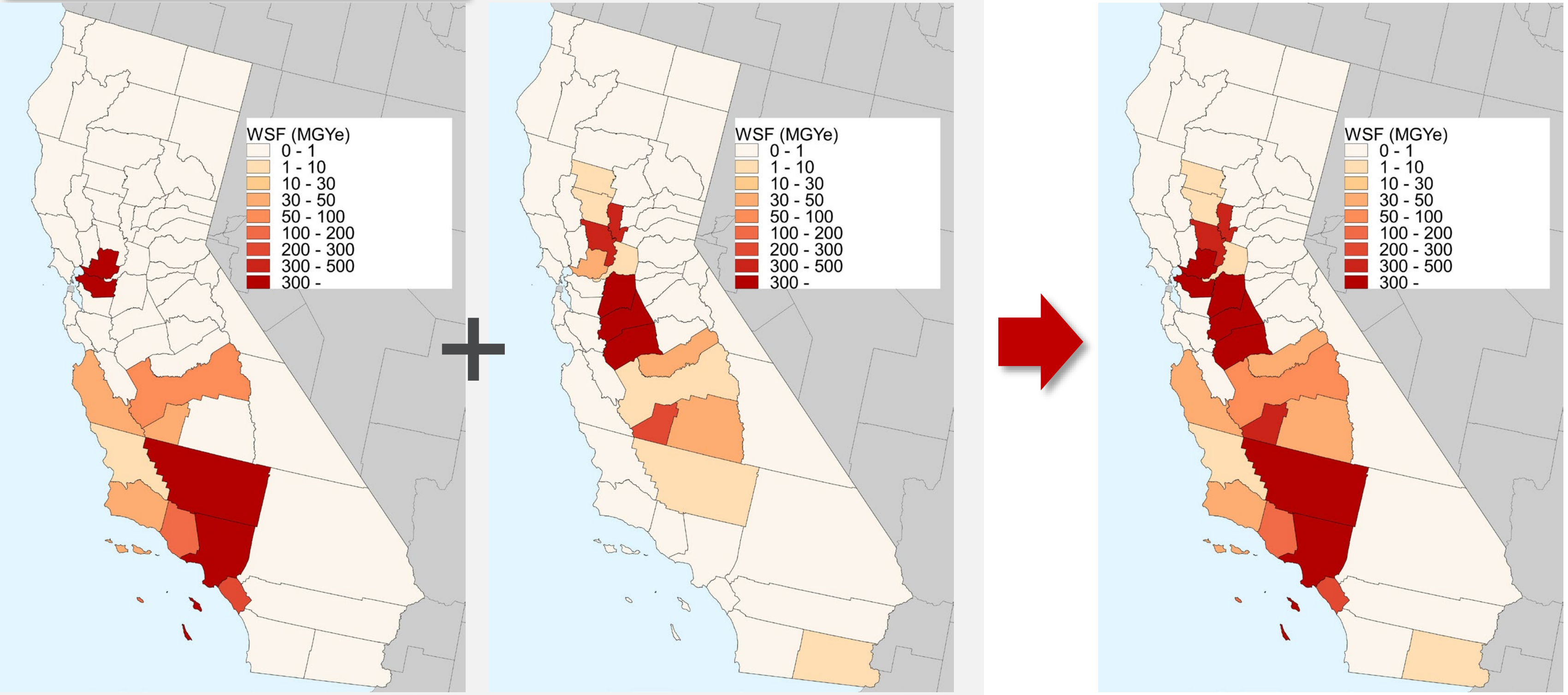
72 MGY

Total **3,086 MGY** of water consumption for E10 production can be avoided

Water scarcity footprint for E10 production

- Considering high water scarcity in many regions in CA, WSF becomes high (on average, AWARE-US CF is 5 for consumed water for E10).

WSF for gasoline | WSF for ethanol | **WSF for E10**



7,568 MGYe | 7,712 MGYe | **15,280 MGYe**

What if H_2 is deployed at scale in various region? Impact analysis on water resources

Water consumption for H_2 production (process-level)

- Water consumed by electrolysis and steam methane reforming
- Upstream water consumption

Regional baseline water supply and demand

- Surface /groundwater supply
- Water demand (human and environmental water demand)

Regional water consumption for H_2 production at scale

Regional water impact analysis

Regional H_2 demand for end use applications

- H_2 deployment scenarios by region
- H_2 demand

H_2 production technologies by region

- Resource availability (natural gas / wind / solar / nuclear)

Acknowledgment

Hydrogen water analysis at Argonne have been supported by DOE's Office of Energy Efficiency and Renewable Energy's Hydrogen and Fuel Cell Technologies Office (HFTO)

Thank You!

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Our models, tutorials and publications are available at:

https://greet.es.anl.gov/

THANK YOU!