UCDAVIS

SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

An Institute of Transportation Studies Program

Renewable H_2 Pathways for California

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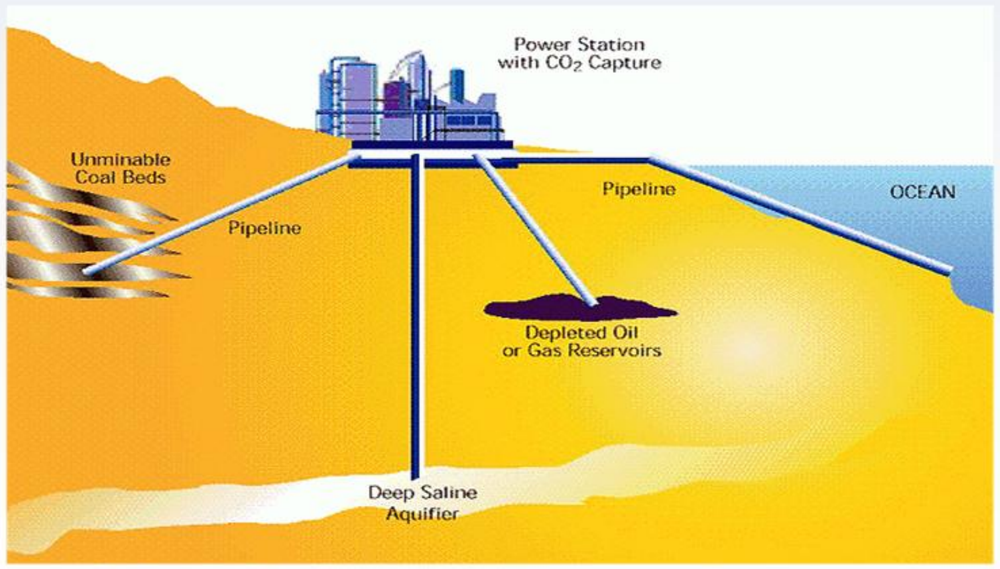
H_2 Supply Pathways

Like electricity, H2 can come from many resources

Wind

Solar

Biomass

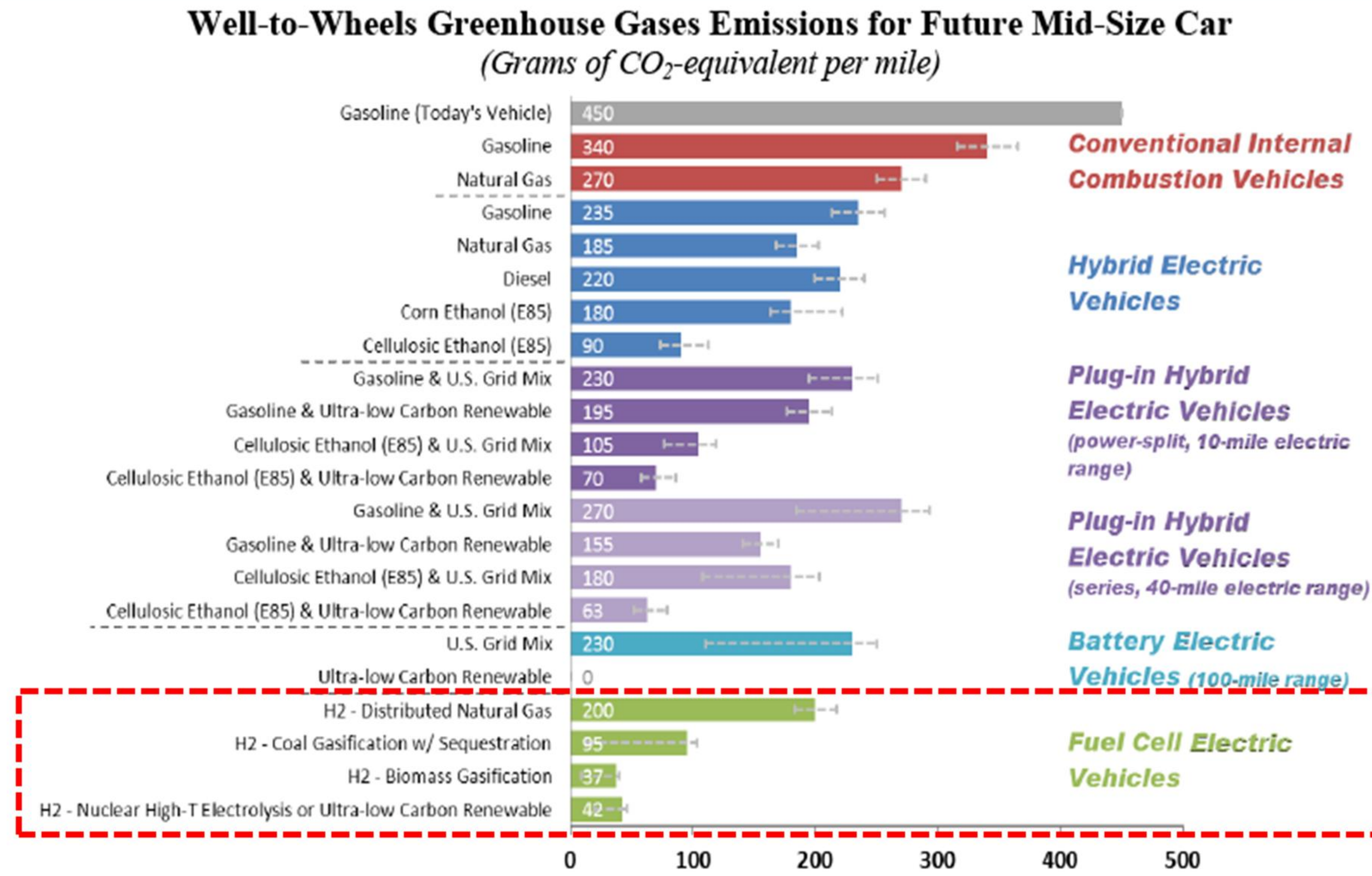


Coal w/CO2 Sequestration

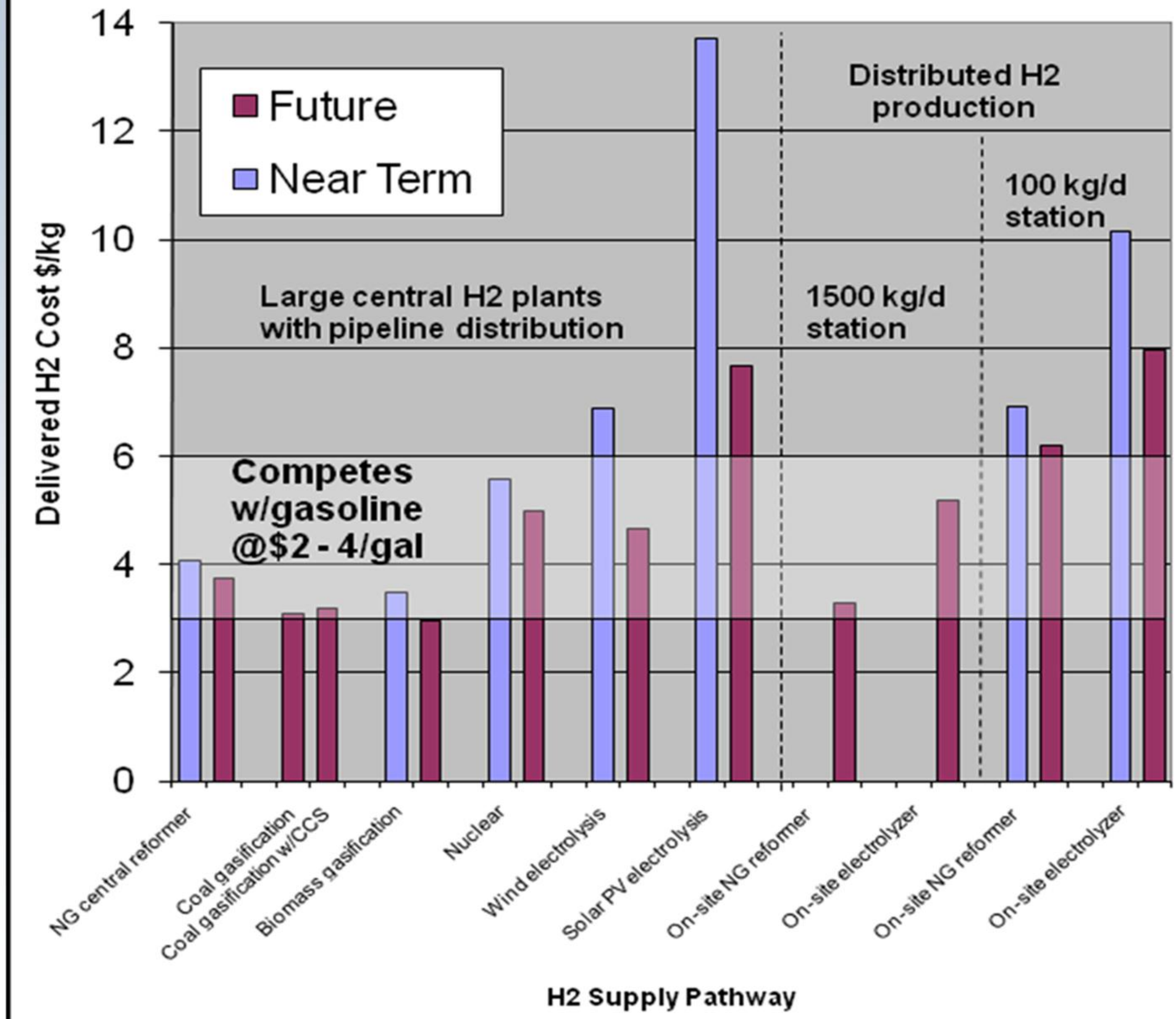
Natural Gas

Nuclear

H2 FCVs have low well to wheel GHG emissions if made from low carbon sources



DELIVERED H2 COST ($/kg)



Near term Renewable H_2 Pathways

- Onsite Reformer using pipeline delivered bio-methane
- Onsite Reformer using bio-ethanol
- Onsite electrolysis (green electricity via grid)
- Onsite electrolysis (Solar PV at station)

33% Renewable H_2 Costs

- **Onsite Reformer w/33% bio-methane** (@$20/MMBTU), **plus 33% green electricity** from the grid at 3 cent/kWh premium (California average green elec. premium).
  - Increases hydrogen cost by about $0.5/kg vs. NG reformer

- **Onsite Reformer with 100% bio-methane and 100% green electricity from the grid** at 3 cent/kWh premium.
  - Increases hydrogen cost by about $1.5/kg

- **Onsite electrolysis w/33% green electricity from the grid at 3 cent/kWh premium**
  - increases hydrogen cost by about $0.5/kg

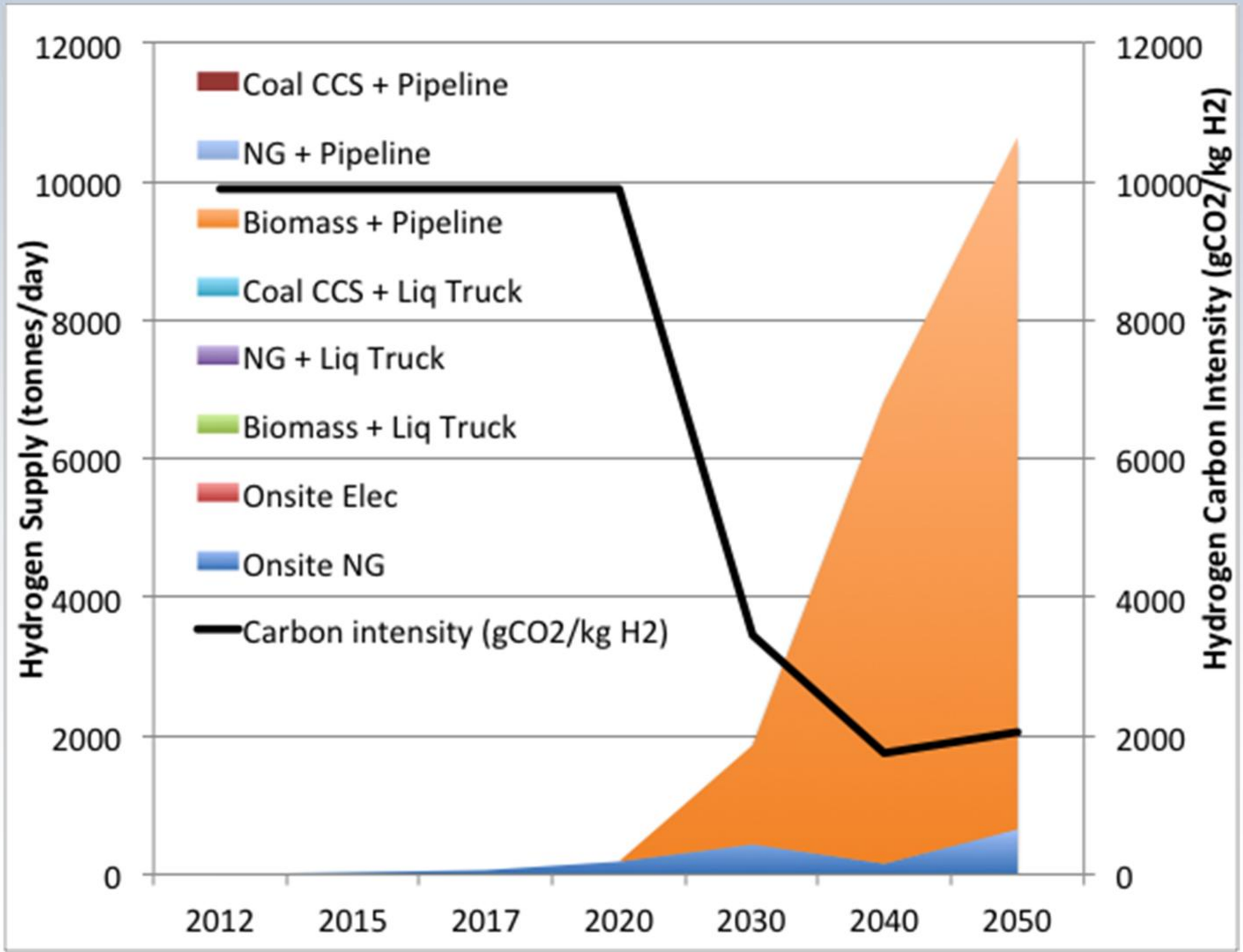
- **Onsite electrolysis w/33% PV electricity** @ 40 cent/kWh
  - increases hydrogen cost by about $5/kg

Long Term Resources for H_2 Production

- **Biomass** (Western Governor's Association study)
  - **High Biomass** 1/3 of WGA supply curve (~43 million dry tonnes) enough to supply 12600 tonnes H2/day serving **~25 million highly efficient FCVs**
  - **Limited biomass supply** : (Assume other uses of biomass take precedence: liquid fuels for aviation, HD trucks marine, etc) – 1/9th of WGA supply curve (~14 million dry tonnes) enough to supply 4200 tonnes H2/day or **~ 8 million FCVs**
- **Renewable electricity (wind, solar)**
  - Up to 354,000 GWh/yr of renewable electricity is available in CA, though at a significant incremental cost
  - =>21500 tonnes electrolytic H2/day or **~43 million FCVs**
- **Natural gas**
  - Early production from onsite SMR
  - Biogas could play an early role
  - Later years:NG should be abundant, but GHG footprint may limit its use
- **Coal w/CCS**
  - Adequate carbon sequestration availability is assumed

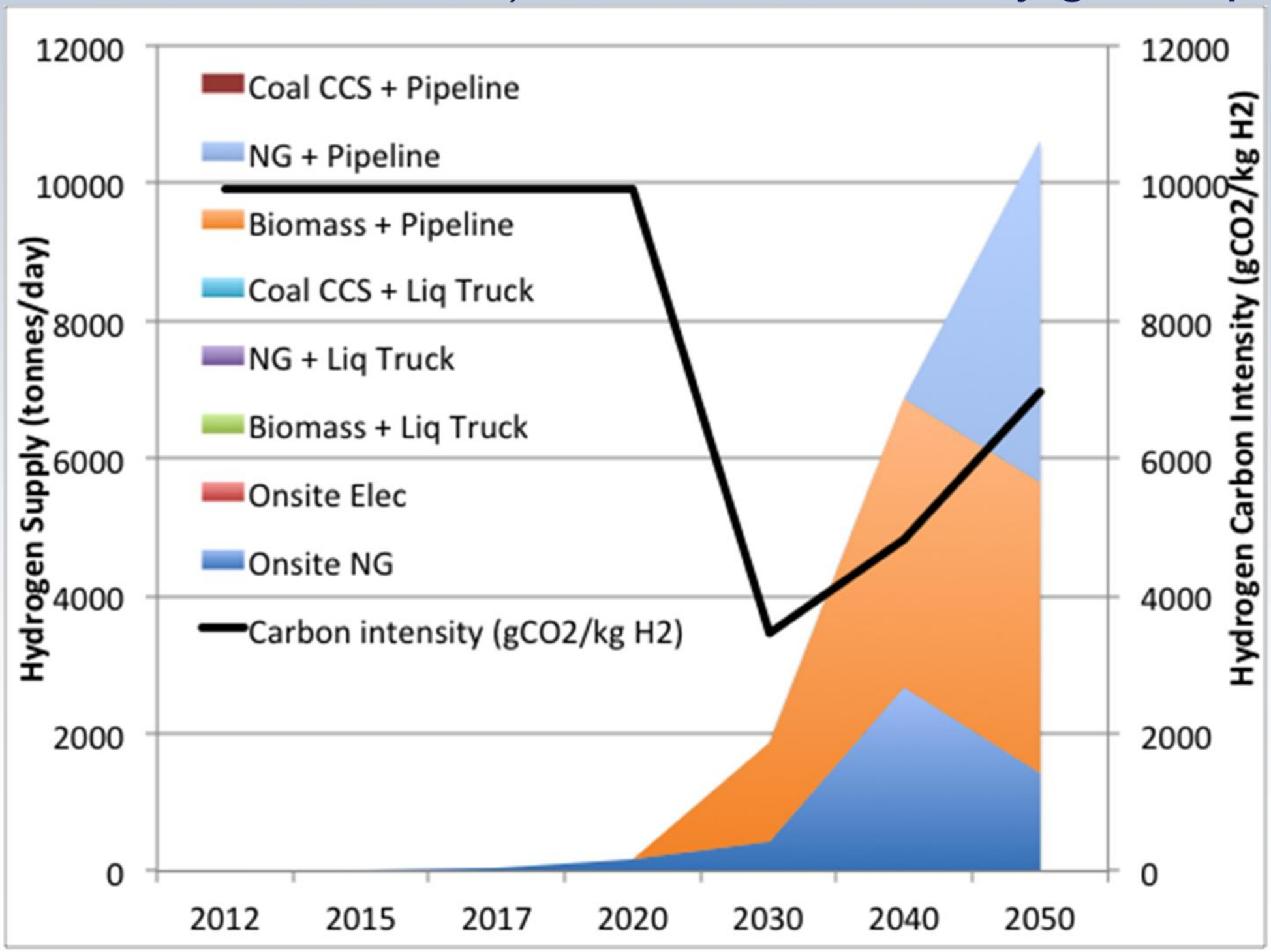
High Biomass Case

- Switch to mostly central production in 2020 which is met by biomass H2 w/pipeline delivery



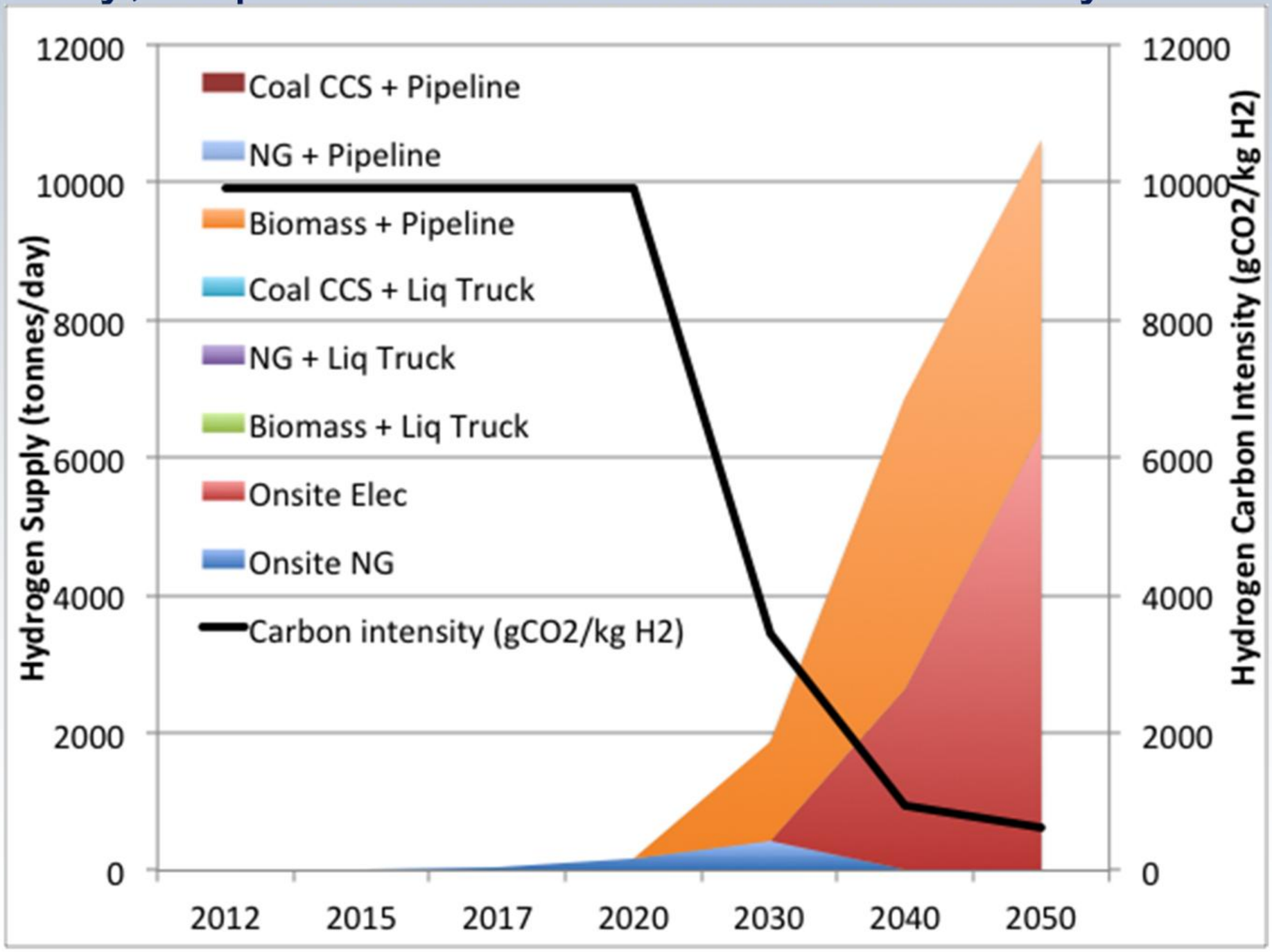
NG Intensive: Limited Biomass, No Coal

- Biomass is the largest H2 source; Major NG use (in both central and distributed) and carbon intensity goes up



Renewable Electrolysis Intensive: Limited Biomass, No Fossil

- NG is phased out in 2040 in order *to lower H2 carbon* intensity, requires lots of renewable electricity



Levelized H_2 Costs Higher for Case w/ Lots of Renewable Electrolytic H_2