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Resourcing Byproduct Hydrogen from Industrial Operations

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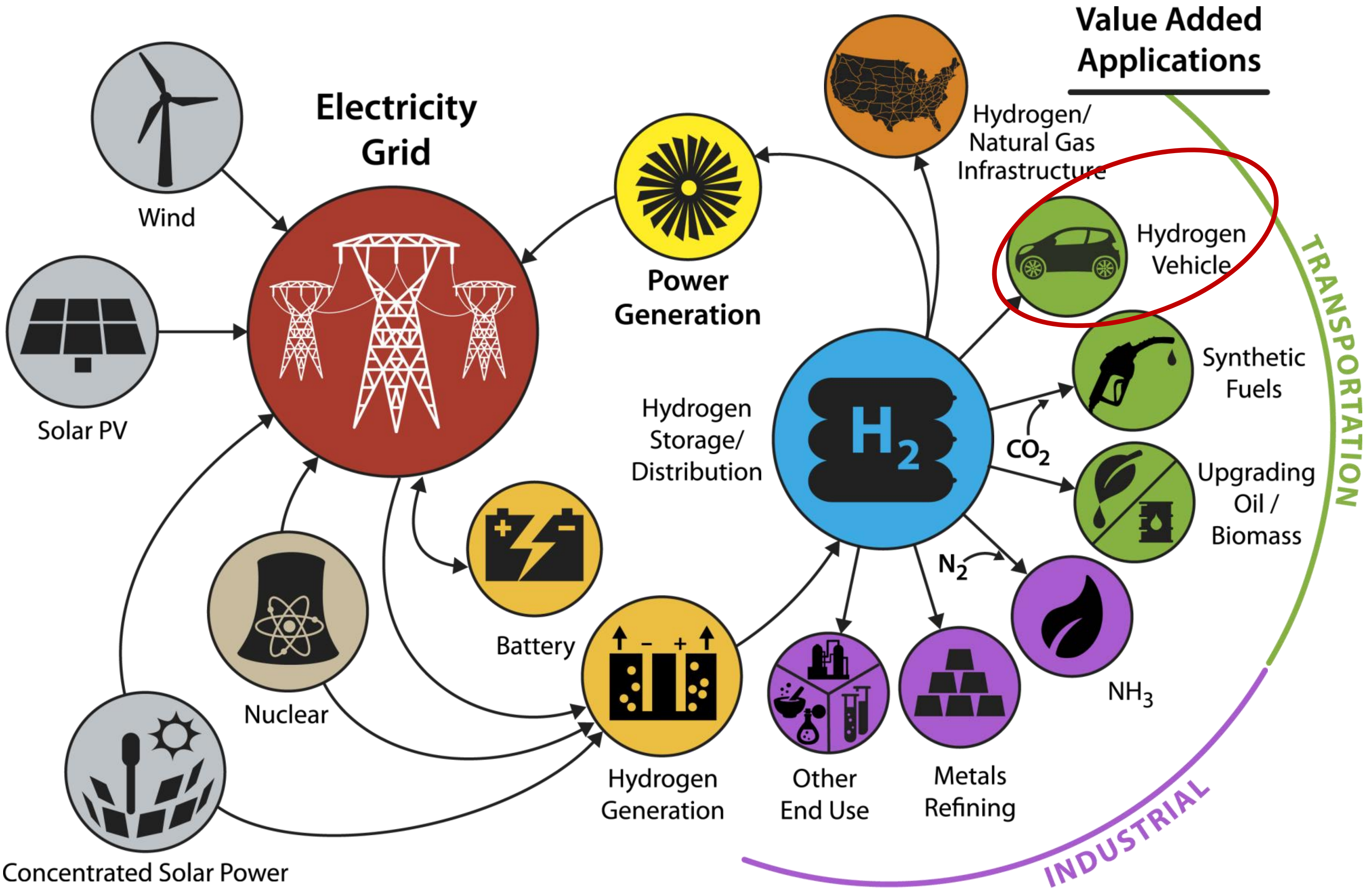
H_2 at Scale Energy System



The demand for hydrogen is expected to grow in the near-term with ramp up of FCEVs deployment

How much hydrogen does a FCEV need each day?

66 mi/kg_H_2

Source: www.fueleconomy.gov

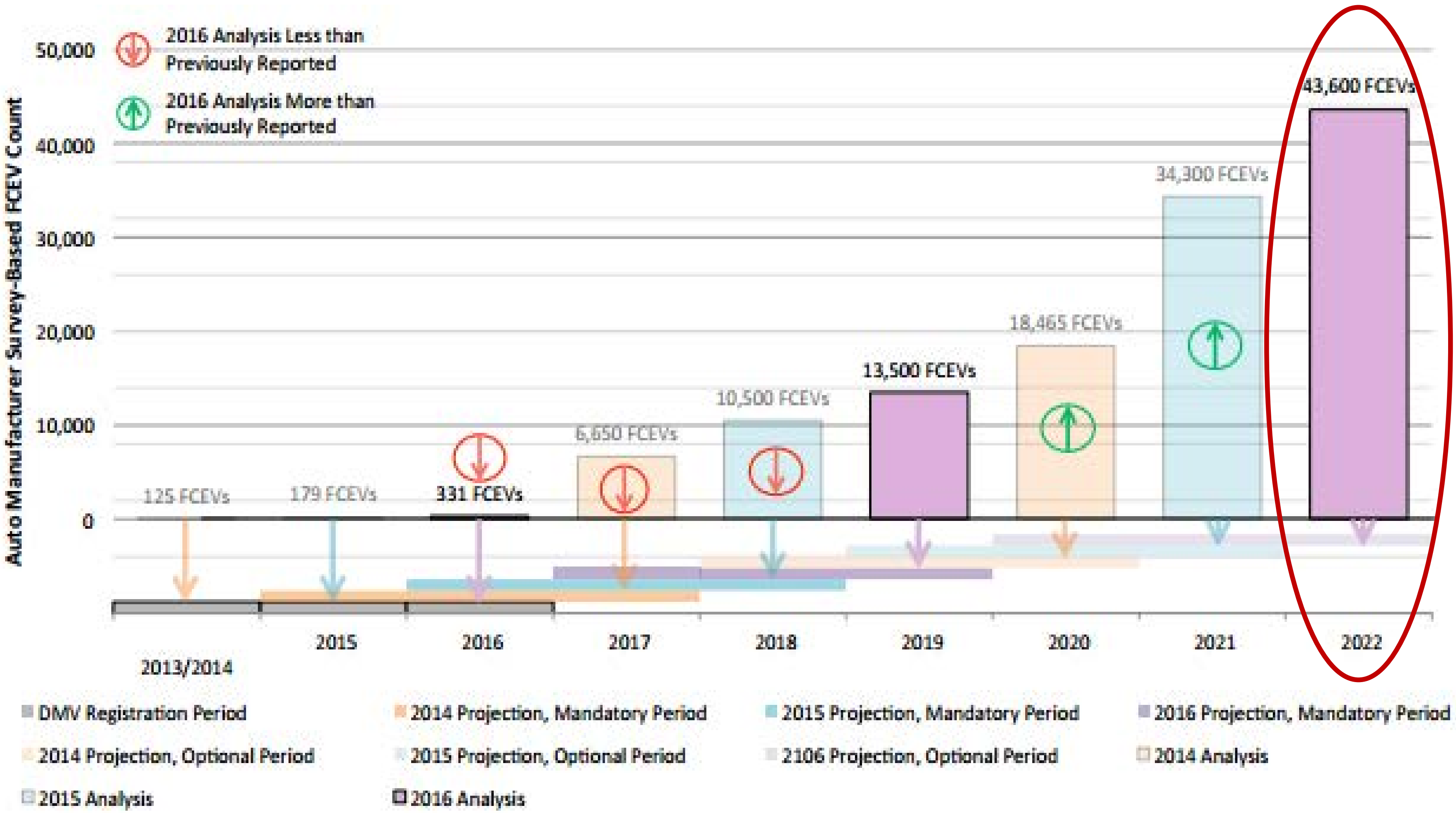
67 mi/kg_H_2

- **Average annual driving distance in the U.S. ~ 12,000 – 13,000 mi**
  - ✓ **~34 miles per day (DOT-FHWA)**

Average FCEV needs ~0.5 kg of hydrogen per day

More than 43,000 fuel cell vehicles in CA within 5 years

Source: CARB (July 2016 report)



Equivalent to more than 20 TPD of hydrogen in CA alone by 2022

Important questions that beg for answers

- Where hydrogen will come from in the near-term? (chicken and egg problem)
- How can we bridge today's production with future large scale hydrogen?
- Are there opportunities than can help the transition (incremental approach) as hydrogen demand grows over time?

Requirements of new hydrogen production sources

- **Large scale production, high purity (>80%)**
- **Low capital investment (low risk), low cost molecules (competitiveness)**
- **Properly distributed where demand exits or is growing**
- **Low adverse environmental impacts**

Possible sources for hydrogen to satisfy growing demand in the near-term

1. Building new SMR hydrogen plants (central or on-site)

2. Utilizing excess capacity in existing merchant hydrogen plants

3. Exploring existing byproduct hydrogen from industrial operations

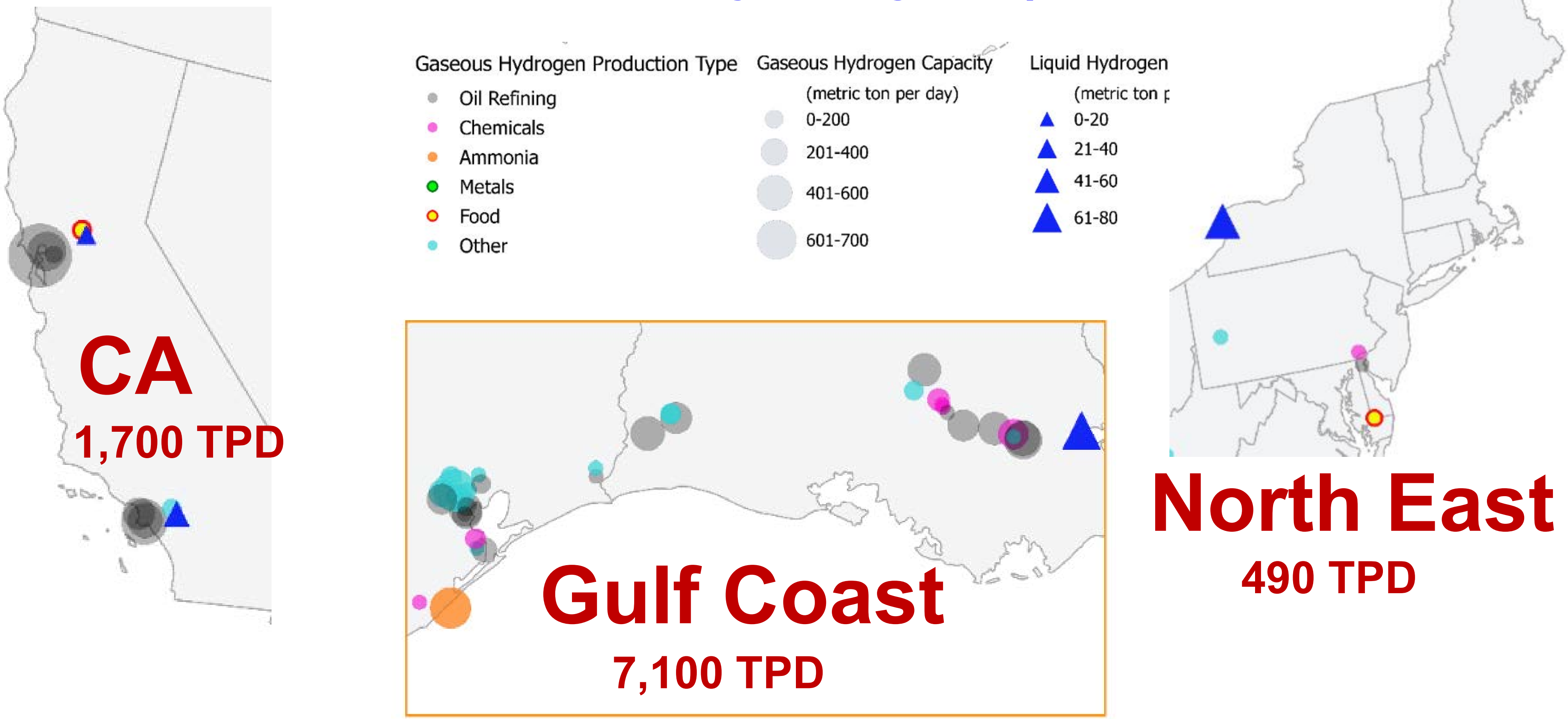
Option 1(a): Building New Central SMR Hydrogen Plants

- Scale: 20-200 TPD
- Requires large capital investment (100s million$)
- Requires demand certainties and long-term contracts (low risk)
- Long lead time to operation (justification, permitting, engineering/design, construction, etc)

Option 1(b): Building New Onsite Hydrogen Plants

- Scale: 0.5-2 TPD
- Shifts the burden and risk to HRS operator
- Requires high utilization of production capacity from day 1
- Challenges with footprint, purification, and other complexity not relevant to the HRS business

Option 2: Utilizing excess capacity in existing merchant hydrogen plants



- Total U.S. merchant H_2 capacity ~ 13,000 TPD, 260 TPD LH_2
- Only 26 TPD in CA and 40 TPD in NY for (non-refinery) customers
  - With 10% excess non-refinery capacity → 6.6 TPD or just 13,000 FCEVs

Option 3: Exploring existing byproduct hydrogen from industrial operations

a. Chlorine Plants → ~1000 TPD of H_2

Process heat   vented

$$2\ NaCl + 2\ H_2O \xrightarrow{e} Cl_2 + H_2 + 2\ NaOH$$

High purity

b. Cracker Plants → more than 7,000 TPD of H_2

Process heat

$$C_2H_6 + heat \rightarrow C_2H_4 + H_2 + \text{other HC}$$

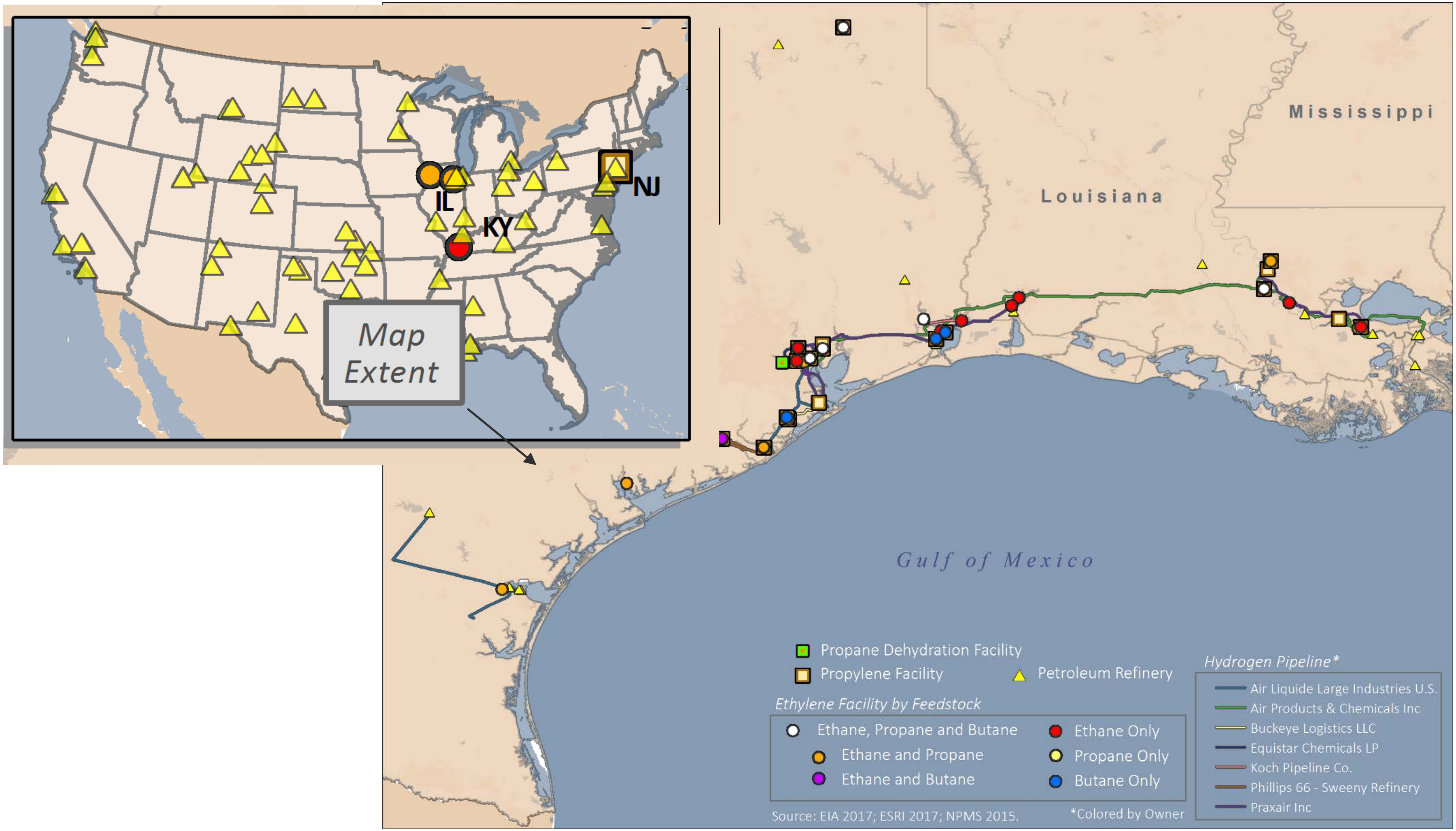
NG

75-90% purity

<u>Option 3</u>: Exploring existing byproduct hydrogen from industrial operations (Chlorine plants)

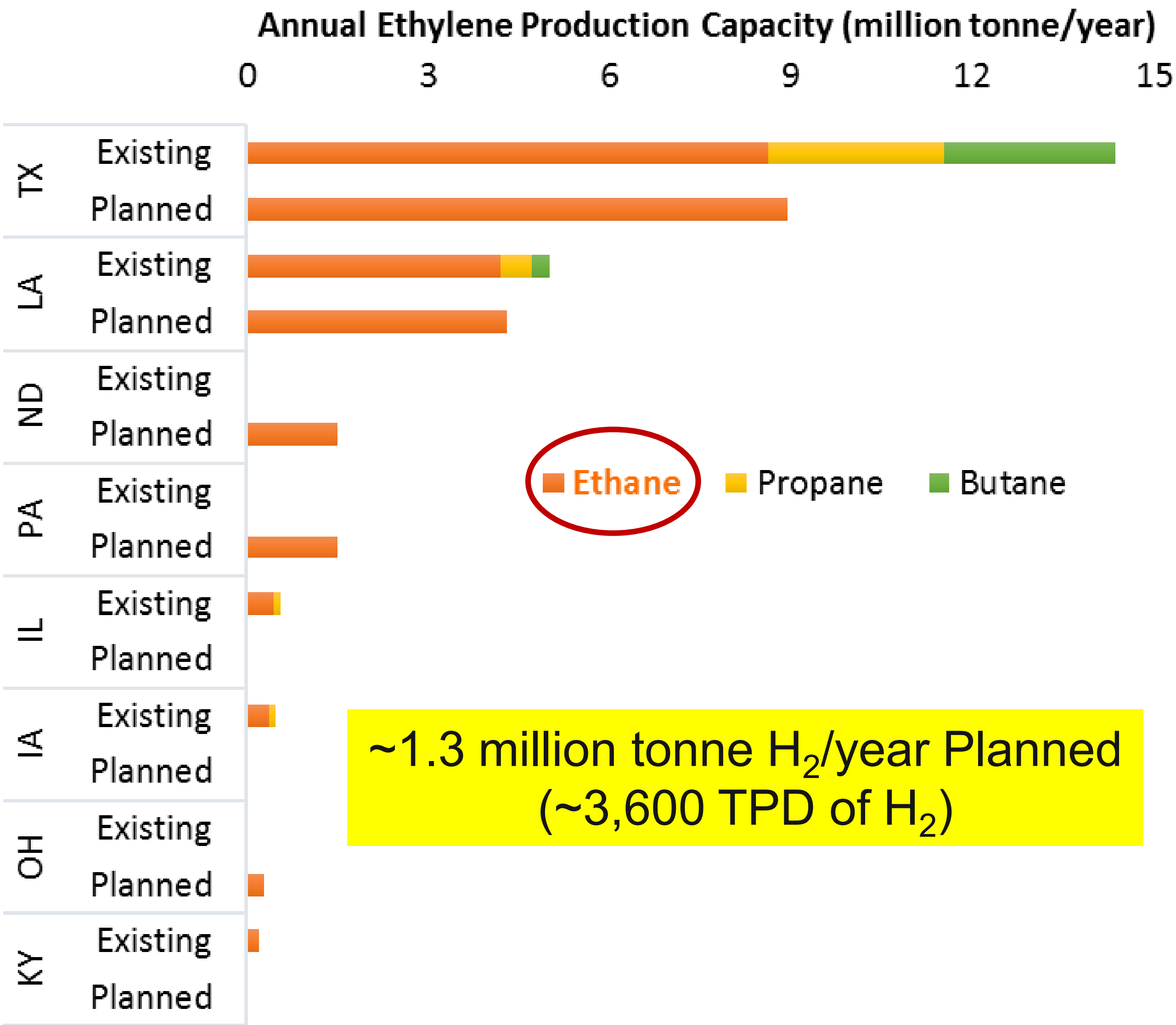
- 46 Chlorine production plants with ~13 million tonne/year chlorine capacity
  - ✓ 0.35 million tonne H_2/year (~1,000 TPD of H_2)

<u>Option 3</u>: Exploring existing byproduct hydrogen from industrial operations (cracker plants)



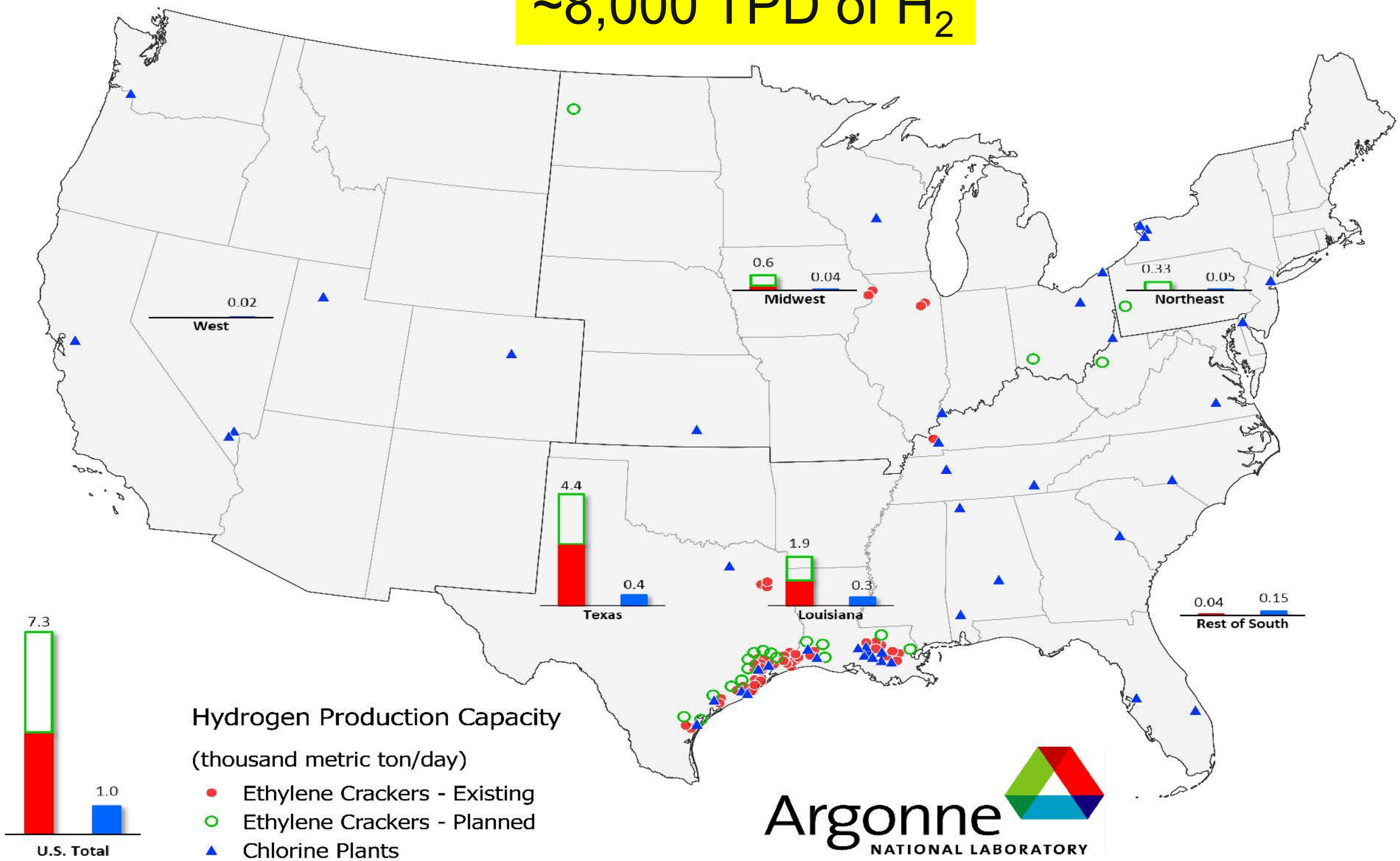
- 51 ethylene production plants with ~20 million tonne/year capacity
  - ✓ 1.3 million tonne H_2/year (> 3,600 TPD of H_2)

Significant cracker capacity addition (>50%) is planned by 2020 (due to low cost NG)



Option 3: Potential byproduct hydrogen from industrial operations

~8,000 TPD of H_2



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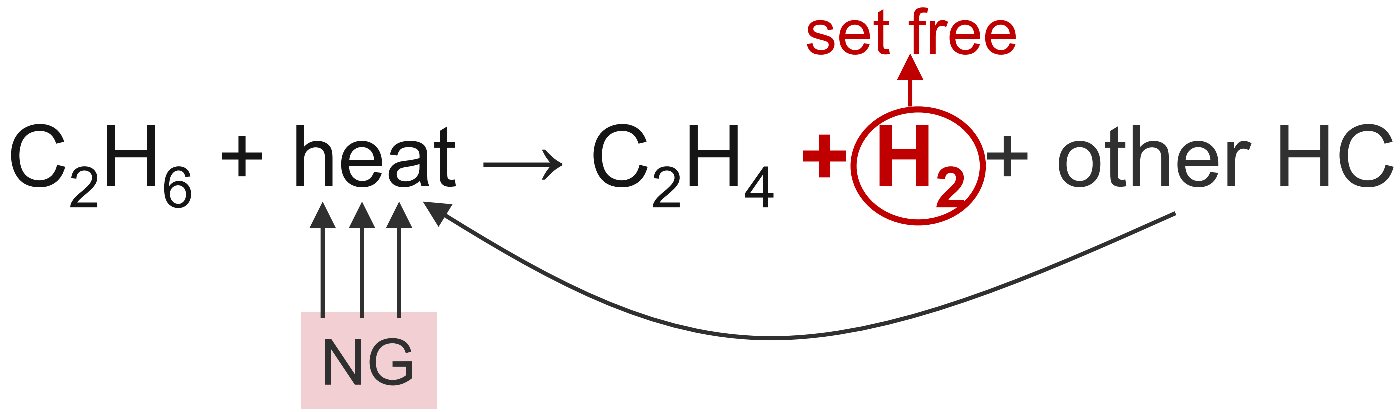
Heating value of H_2 in the fuel gas to satisfy process heat can be replaced with NG



- Hydrogen burned for its Btu value can be replaced with supplemental NG
- 1mmBtu of NG ~ $3-4
  - cost of displaced H_2 ~ $0.3-$0.4/kg_{H2}
- Cost of PSA purification is ~$0.1-0.2/$kg_{H2}$
  - ✓ Cost of purified hydrogen ~ <u>$0.5-$0.6/kg_{H2}</u>
  - ✓ Cost of H_2 compression is additional

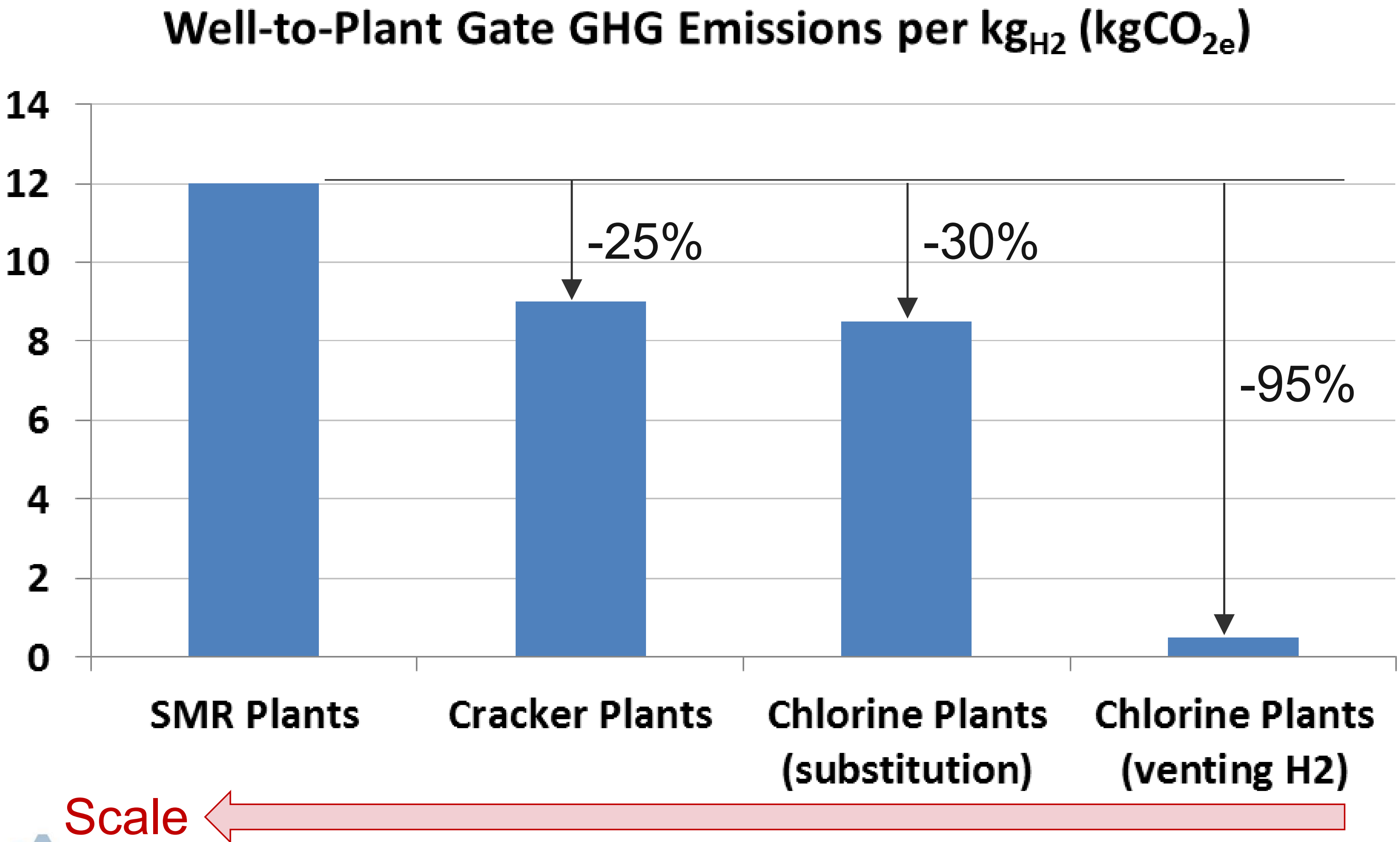
Hydrogen Produced from Crackers is Low Carbon Fuel

SMR: 1.4-1.5 Btu NG → 1 Btu H_2

Crackers: 1 Btu NG → 1 Btu H_2

- Lower GHG emissions than H_2 from SMR
  - ~30% less GHG than SMR H_2
  - Other LCA methods result in lower GHG emissions

Low GHG emissions of byproduct hydrogen



Incentives in CA promote low-carbon hydrogen

Time Period	Transfers [1] (number)	Total Volume[1 2] (credits-MTs)	Avg. Price[1 3] ($ per Credit)
CY 2016	929	5,343,000	$101
CY 2015	578	2,852,000	$62
CY 2014	304	1,667,000	$31

Source: https://www.arb.ca.gov/fuels/lcfs/credit/20170509_aprcreditreport.pdf

LCFS Credit Values for Selected Representative H_2 Pathways

	100% Renewable Electrolysis [A]	100% Dairy Biomethane SMR [B]	100% Biomethane SMR [B]	33% Biomethane SMR [A]	Natural Gas SMR (Gaseous H2) [A]	Natural Gas SMR (Liquified H2) [A]
CI Score (gCO2e/MJ)	0	-300	54	88	106	144
FCEV EER-adjusted CI	0	-120	22	35	42	57
Credit Value ($/kg)	$2.90	$6.50	$2.25	$1.84	$1.62	$1.17

1 kg ≈ 1.04 GGE

[A] Certified LCFS Pathway

[B] Staff Estimate

Source: Sam Wade, CARB presentation at CHBC 2016

Check points for byproduct H_2

- ✓ Large scale production, high purity (>80%)
- ✓ Low capital investment (low risk), low cost molecules (competitiveness)
- ✓ Properly distributed where demand exits or is growing
- ✓ Low adverse environmental impacts

Thank you

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