H2-W
The producers value of Water in a Hydrogen Economy

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Project ID #
AN7

Overview

Timeline

- Start: Sept 07
- End: Oct 08
- Percent Complete: 75%

Budget

- Total project funding
  - DOE $440K
- Funding received in FY07
  - $200K
- Funding for FY08
  - $240K

Barriers

- Future Market Behavior (A) Market Transformation
- Inconsistent data, assumptions and guidelines (C)
- Unplanned Studies (E) - Resource Requirements and Availability

Partners/Collaborators

- UC Davis ITS (Model Parameterization)
- LBNL (L.Dale)
- Sandia (M. Hightower)
- NREL(M. Ruth)

Project Objectives

- Characterize the water requirements for hydrogen production
  - Asses the water requirements inside the H2 plant
    - Water intensity
    - Water quality
    - Impact of water on H2 costs
  - Asses external water requirements in support of H2 Production
    - Embedded water of input resources
    - Source reliability (quantity and quality)
    - Regional water influences
- Develop framework for assessing the impact of water in hydrogen production
- Comparative analysis with water use for other fuel options
- Evaluate regional conditions that may impact adoption hydrogen production for a particular region

Approach: Background

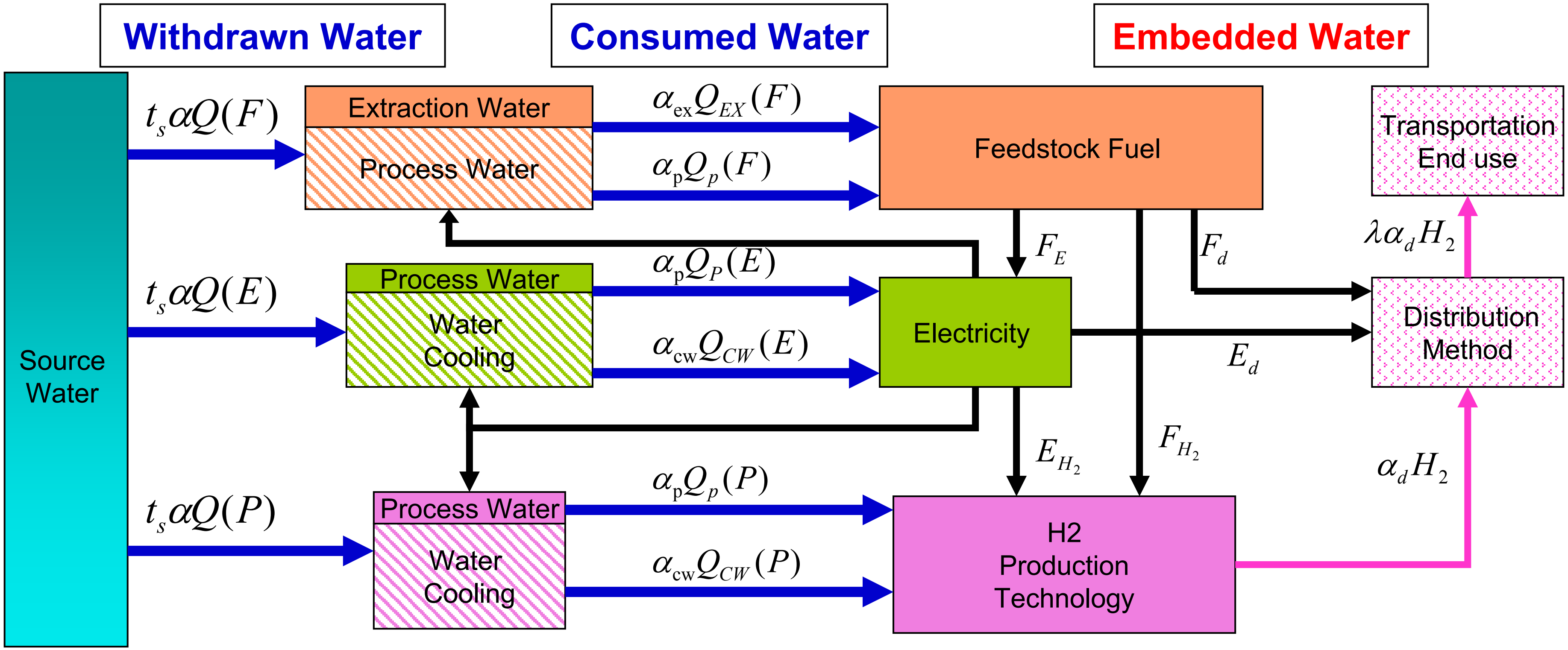
Frame problem of water requirements as a decision opportunity for a hydrogen producer

- Balance Energy - Water tradeoffs
  - Design plant assuming water “may” be a critical resource
  - Regional dependent problem
- Broaden scope of planning problem to infrastructure not typically included
  - Similar to a Wheel-To-Wheels(WTW) approach with the added complexity of water reuse.
  - Assess water withdrawal, consumption and reuse vs. return
- Decision variables :
  - Production method
  - Electric source
  - Cooling technology
  - Water reuse

Assumptions

- Hydrogen production at scale requires development of supporting infrastructure (e.g. electricity generation, water pre and post-treatment, water conveyance and acquisition) that is not required small scale
- Electricity can be produced by a variety of methods
- Water value and cost and may be different in different regions of the country and might influence the choice of technologies

Approach: H2-Water-Balance



E = Electric ity Generation Tech

F = Fuel Type

P = Hydrogen Productio n Tech

α_p = Process Water Coefficien t

α_{cw} = Cooling Water Tech Coefficien t

t_s = Water Treatment Coefficien t

Q_P = Process Water Requ irement

Q_{CW} = Cooling Water Requ irement

E_p = Electric ity Consumed in H_2 Productio n

F_P = Fuel Consumed in H_2 Productio n

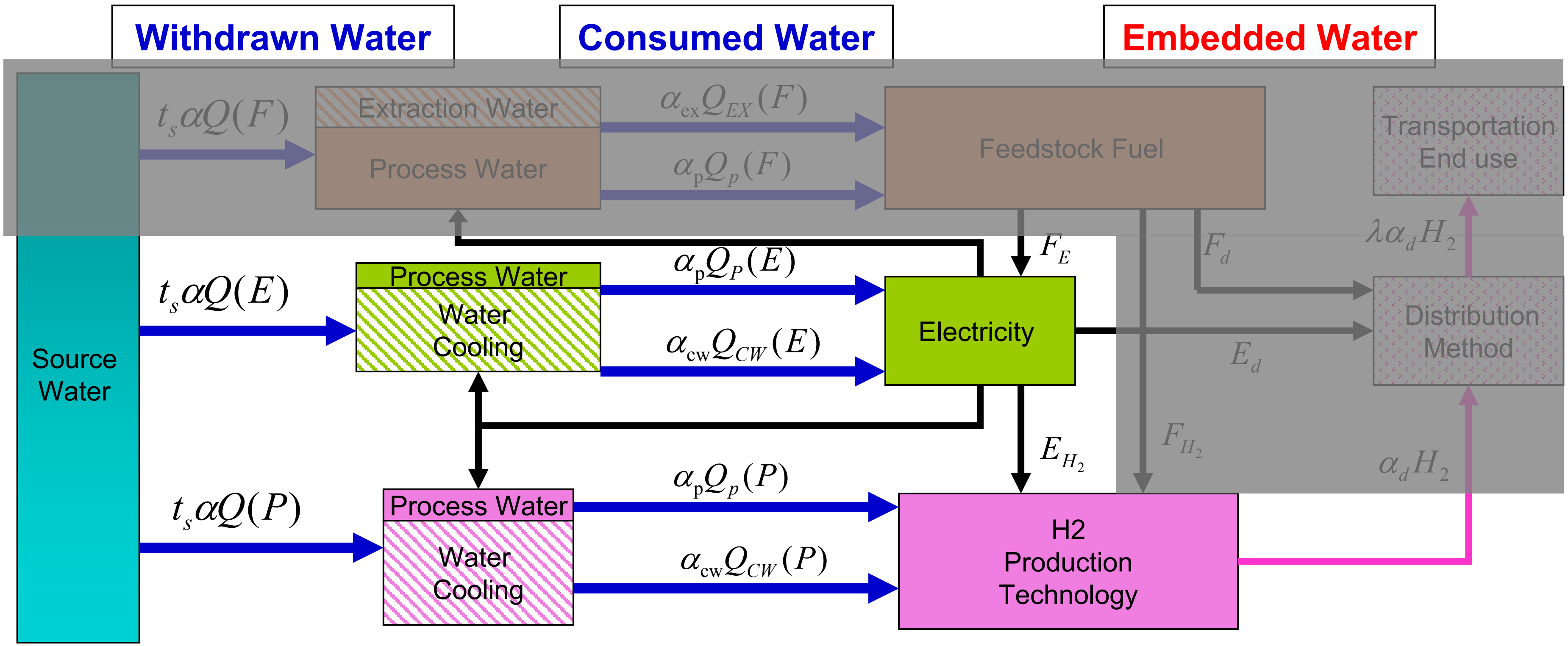
H_2 = Hydrogen produced

α_d = H_2 Distribut ion Coefficien t

λ = End - Use Efficienc y

H2W - Hydrogen - Water Nexus Model

The Hydrogen-Electricity-Water Pathway



- Significant quantity of electricity is needed for input to electrolysis process ↔ Hydrogen producers have choice of electricity source
- Cooling water in electricity generation can be large ↔ Opportunity for water savings utilizing newer technology

H2 Pathways Examined:

DOE Hydrogen Program

Fuel Production Intensities

Technology	Process Water Q_P (gal/kg)	Process Electricity E_P (kWh/kg)	Process Fuel F_p (MMBTU/kg)	Process Cooling Q_{CW} (gal/kg)
SMR Forecourt Air Cooled	1.1 - 1.3	3.7	0.17	n/a
SMR Forecourt Water Cooled	1.1 - 1.3	3.2	0.19	123
SMR Central	1.0 – 1.3	0.55 - 0.8	0.15	
Electrolysis Forecourt	2.4 - 2.7	55 - 81	n/a	
Gasoline	1 - 2.5			

Sources: NREL 2002 *Hydrogen Supply: Costs Estimate for Hydrogen Pathways - Scoping Analysis: H2Gen Manufacture Specification: H2A Forecourt Electrolysis : Energy Demands on Water Resources: Report to Congress on Interdependency of Energy and Water 2006:*

Source Water Treatment Efficiencies

Water Treatment Technology	Coefficient t_s
Reverse Osmosis Brackish	1-1.5
Reverse Osmosis Saline	2 - 9
Ion Exchange	1:1

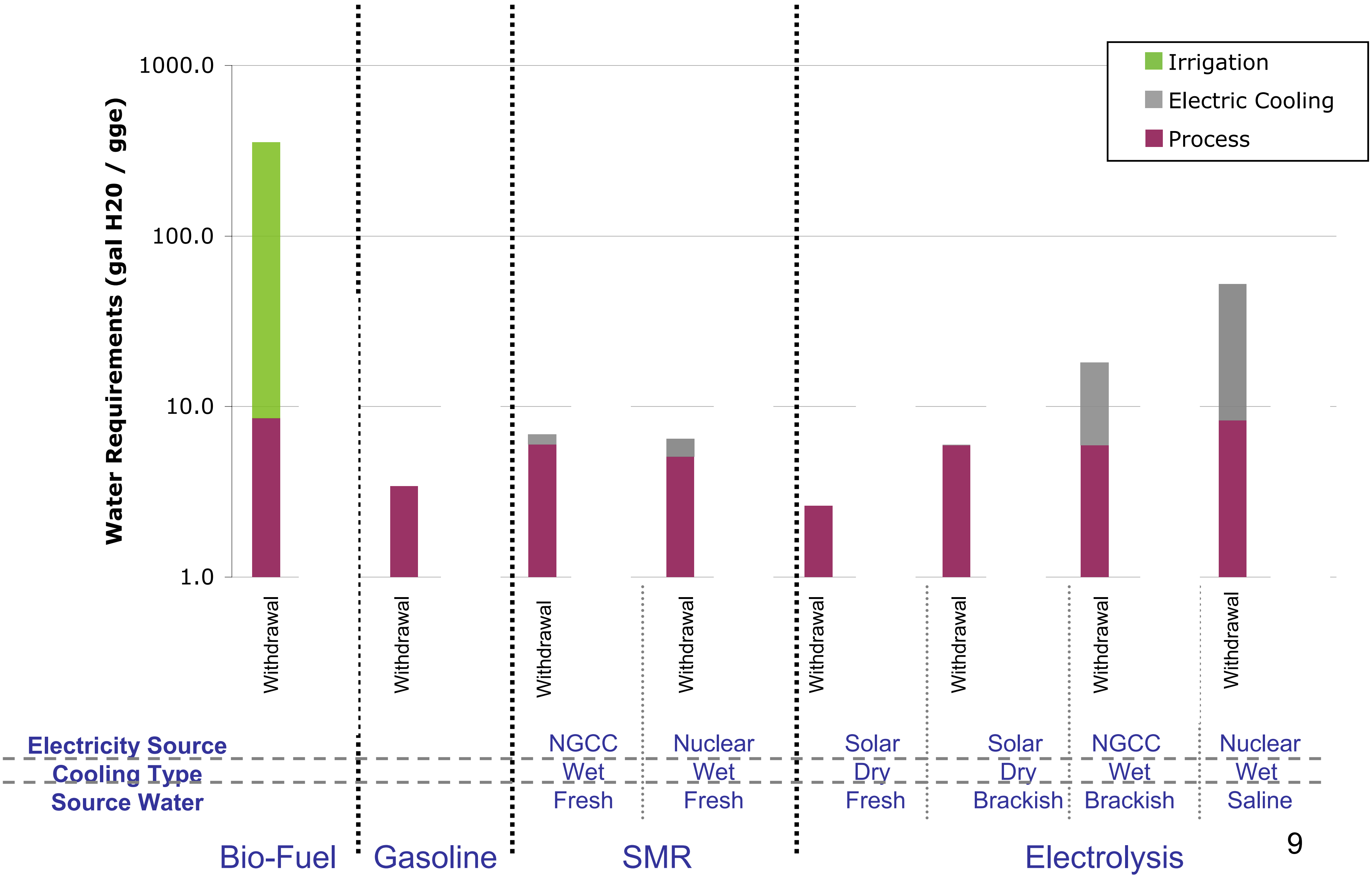
Sources: GE *Manufacture Specification: Personal communication*

Power Plant Cooling Parameters

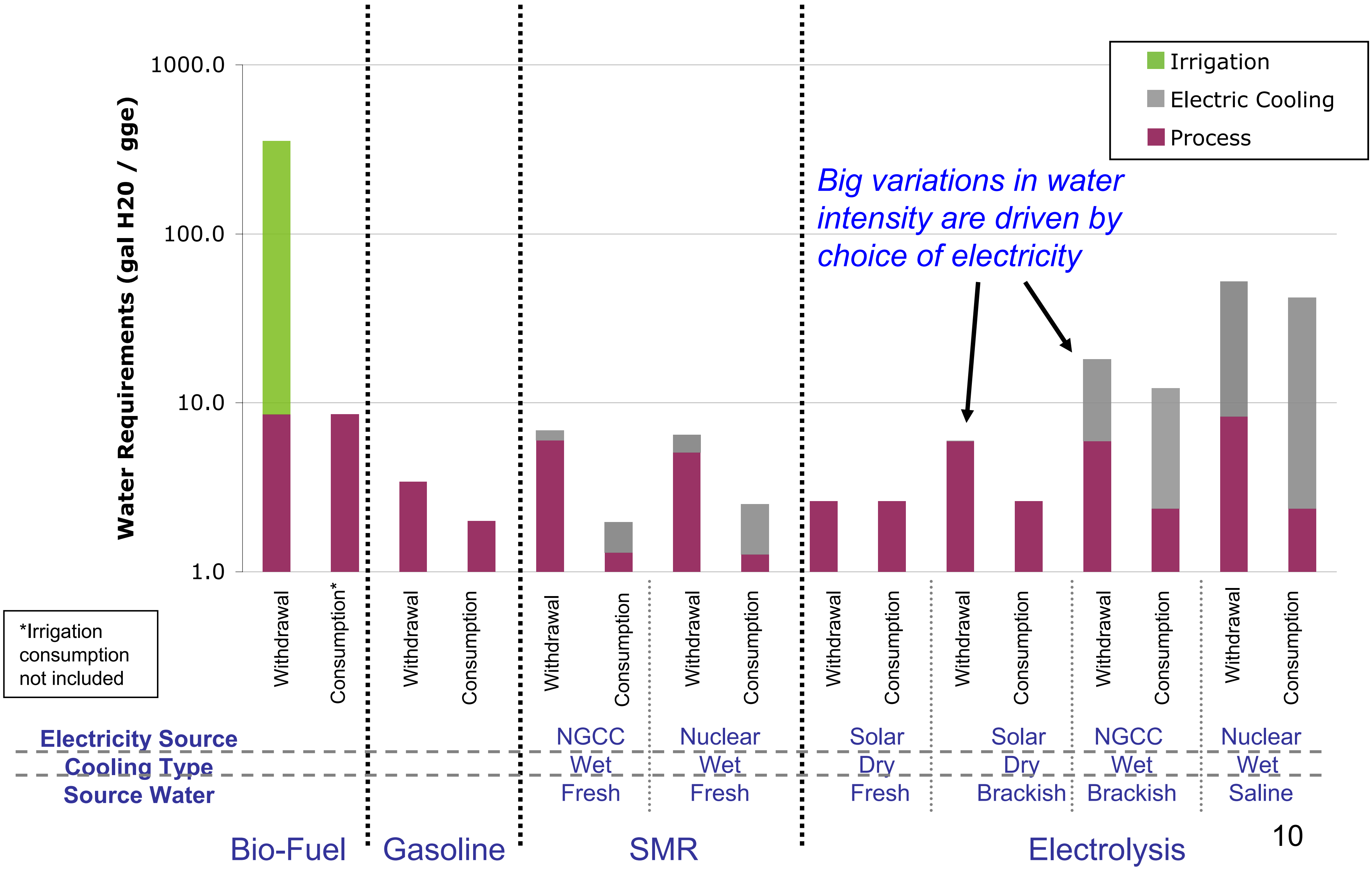
Cooling Type	Requirement Q_{CW}(E) (gal/kWh)	Coefficient α_{CW}
Once Through	0.1 - 0.5	60 - 200
Wet	0.18 -1.4	1 - 1.5
Dry	0	1

Source: *Energy Demands on Water Resources: Report to Congress on Interdependency of Energy and Water 2006*:

Water Intensity Preliminary Results:



Water Intensity Preliminary Results:



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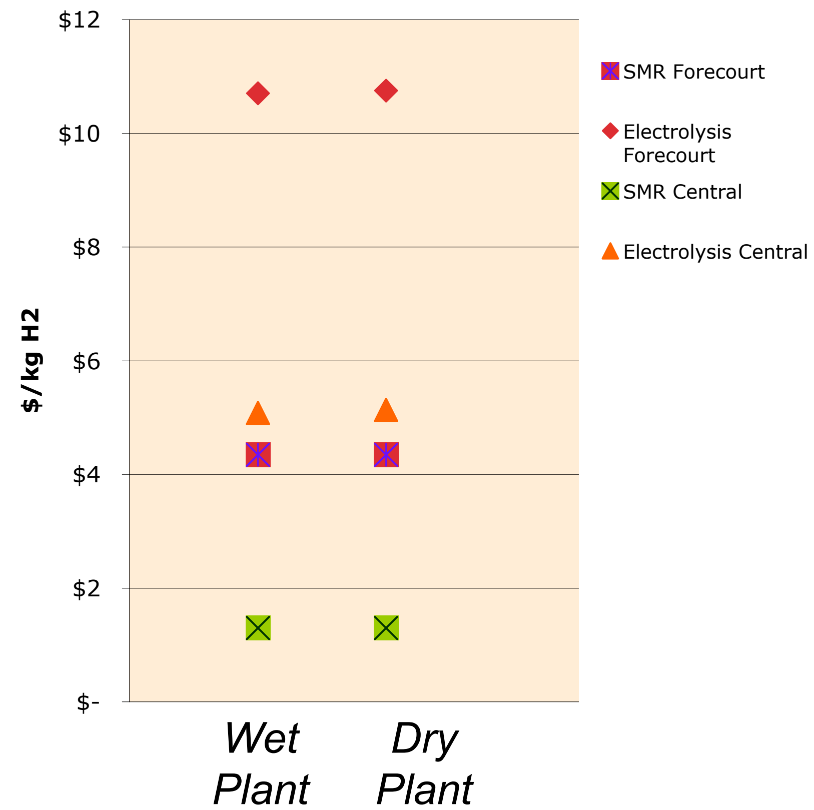
Hydrogen Water Economics Preliminary Results:

Water Intensity of electricity can be reduced with minimal impact on H2 price

- *Changing a 500 MW NGCC from Wet cooling to Dry cooling plant has annualized change in producers cost of electricity of +3% $/kWh*

- *Change in retail electric price would be more due to mark-ups*

- *Change in cost of hydrogen production*
    - *2% for Electrolysis*
    - *>1% for SMR*

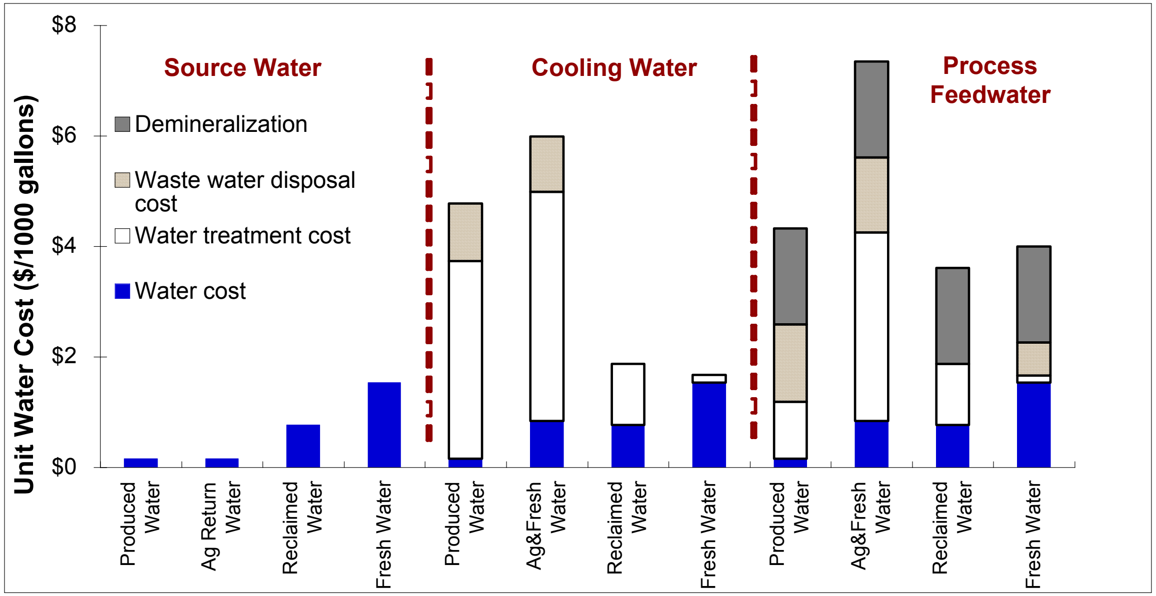


Sources: NREL *Hydrogen Supply: Cost Estimates for Hydrogen Pathways –Scoping Analysis* 2002 . *Cost and Value of Water Use at Combined-Cycle Power Plants,* California Energy Commission, 2006.

The Value Of Water (VOW) for a hydrogen producer

Cost of Water Supply

- Regionally/source dependent cost
- $0.2 - $8 per 1000 gal minimum requirement



Equivalent Cost of Water (I.e. cost of recycling)

- $3.3 - $6.1 per 1000 gal in CEC study
- Regionally and climatically dependent
- Compare technologies with this method

Residual Imputation

- VOW = Revenue - Non-water costs
- Requires assumption about hydrogen demand
- Under development

Improved estimates of the value of water will improve decisions regarding water dependent technology investment

H2-W

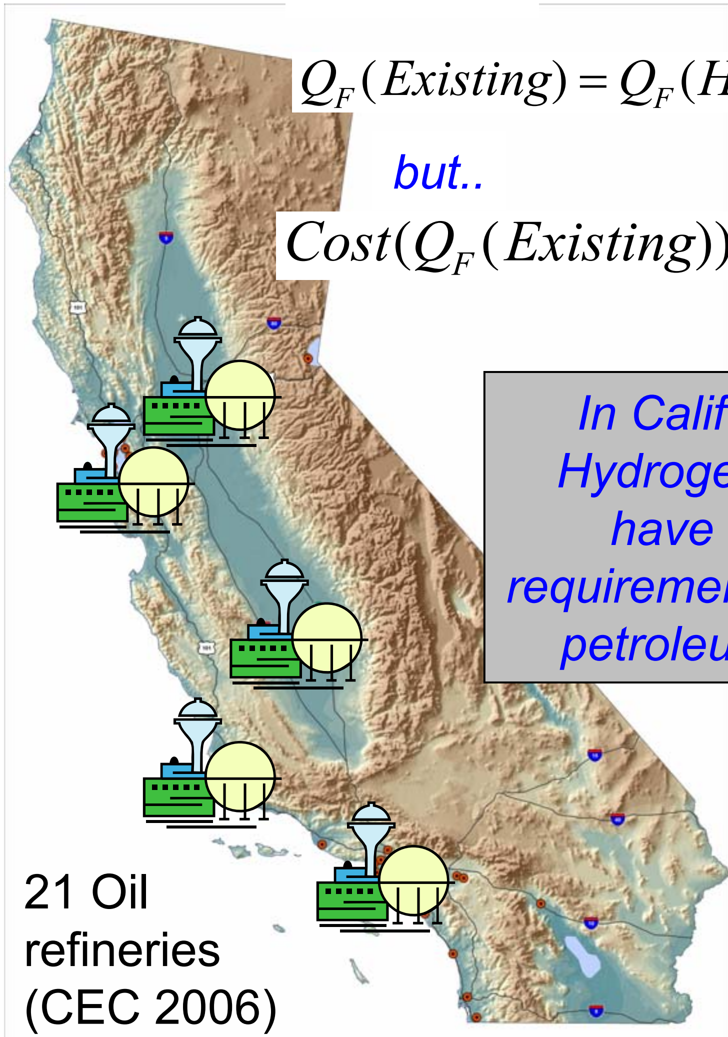
Regional geography influences how water can be utilized in fuel production

Assume ..

$$Q_F(Existing) = Q_F(Hydrogen)$$

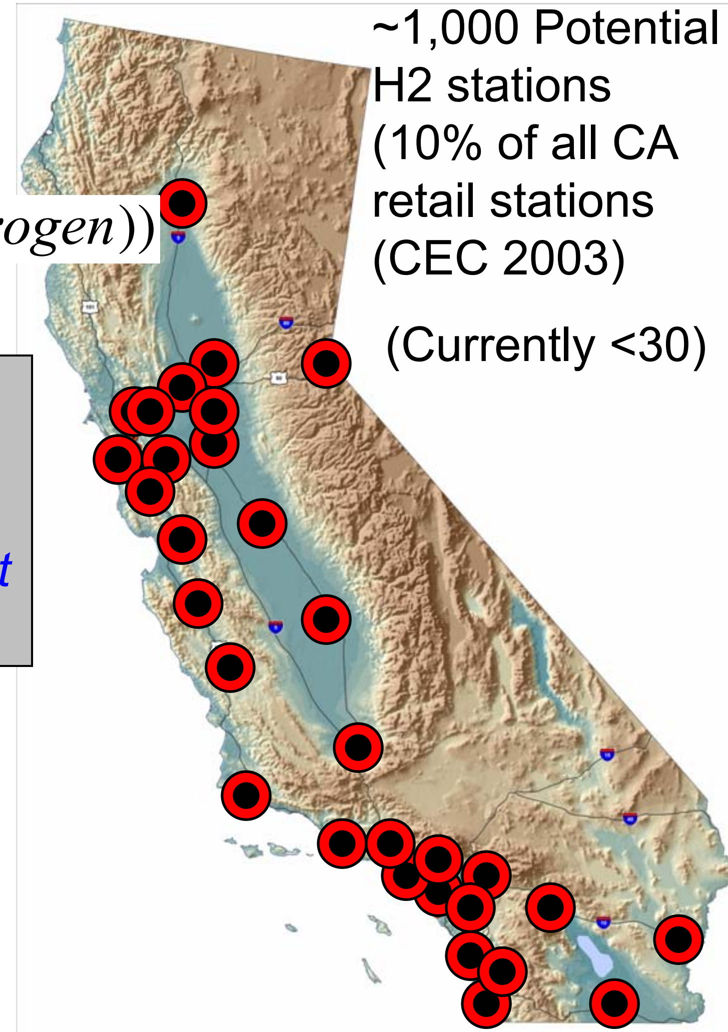
but..

$$Cost(Q_F(Existing)) \neq Cost(Q_F(Hydrogen))$$



21 Oil refineries (CEC 2006)

In California, Forecourt Hydrogen generation will have different water requirements than the current petroleum infrastructure.



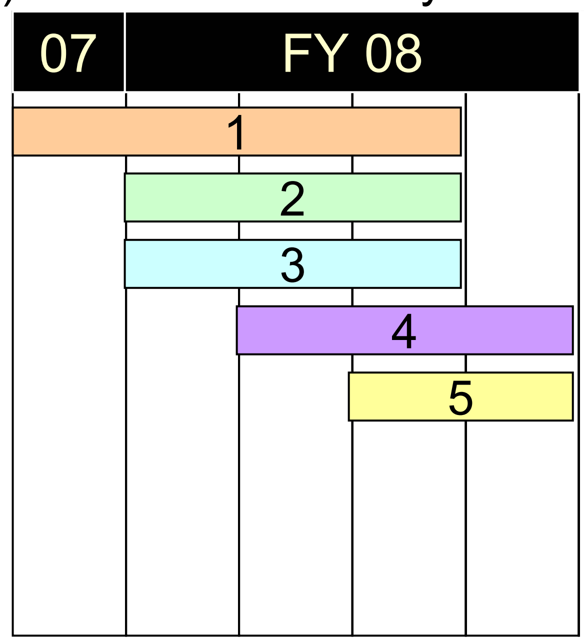
~1,000 Potential H2 stations (10% of all CA retail stations (CEC 2003)

(Currently <30)

Current Progress

Tasks:

1) Develop analysis of water requirements
   Literature Search, Systems models development
2) Determine engineering parameters and commercial constraints
   Asses data quality and inconsistencies across previous studies
3) Determine preliminary economics
   Assess value of alternative technologies, sensitivity analysis
4) Assess key regional scenarios and solutions
   Regional analysis water supply cost curves
5) Assess and identify climate change concerns.



Proposed Future Work

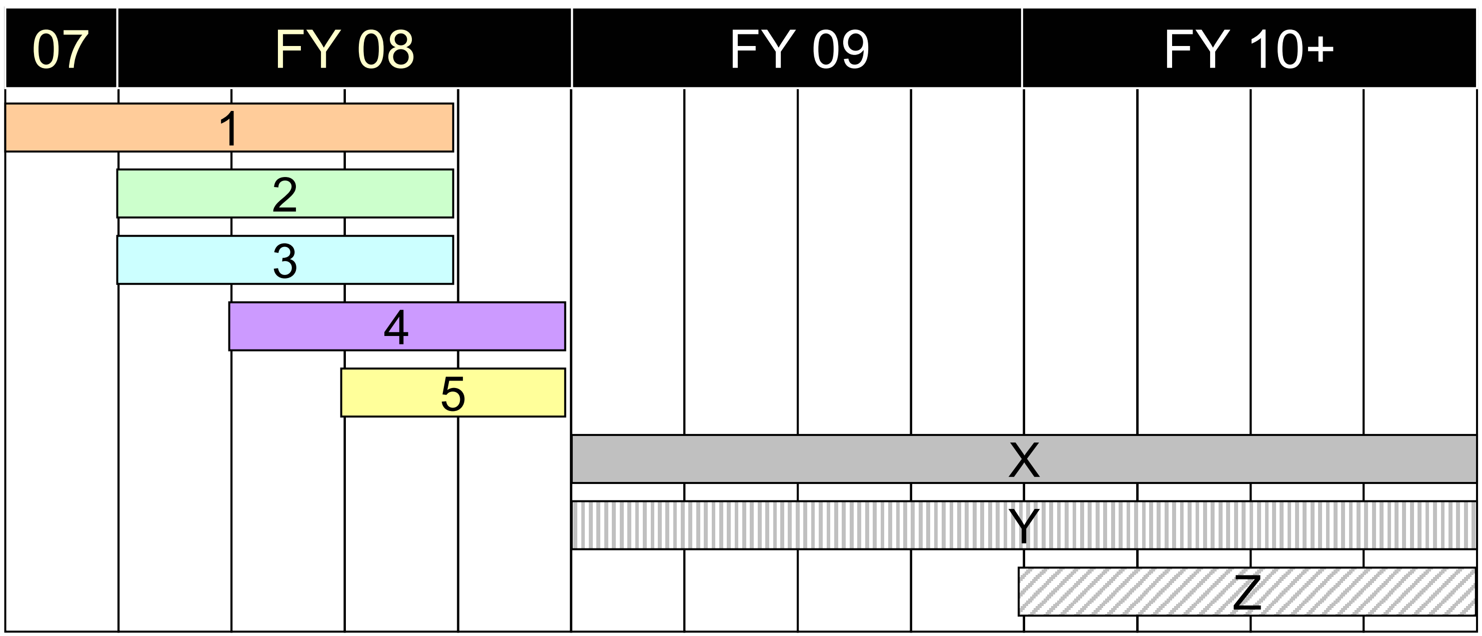
Tasks:

1) Develop analysis of water requirements
2) Determine engineering parameters and commercial constraints
3) Determine preliminary economics
4) Assess key regional scenarios and solutions
5) Assess and identify climate change related concerns

X) *Integration with MSM*

Y) *Data collection through coordinated metering*

Z) Regional Geographic Hydrogen-Water Benchmarking Scorecard



Summary

- **The H2-W framework extends the bounds of water impacts in the hydrogen production life cycle**
- **Electricity can be the biggest water user in the hydrogen production life cycle**
- **Hydrogen-water intensity can be kept low with new technology at small cost relative to cost of hydrogen**
- **Price, Value, and Availability of water to a producer will be dependent on the geographic location**
- **Water can be recycled more easily than other resources like gasoline, or C02**