Gasification & Water Nexus

GTC

Workshop on Gasification Technologies
Denver, Colorado

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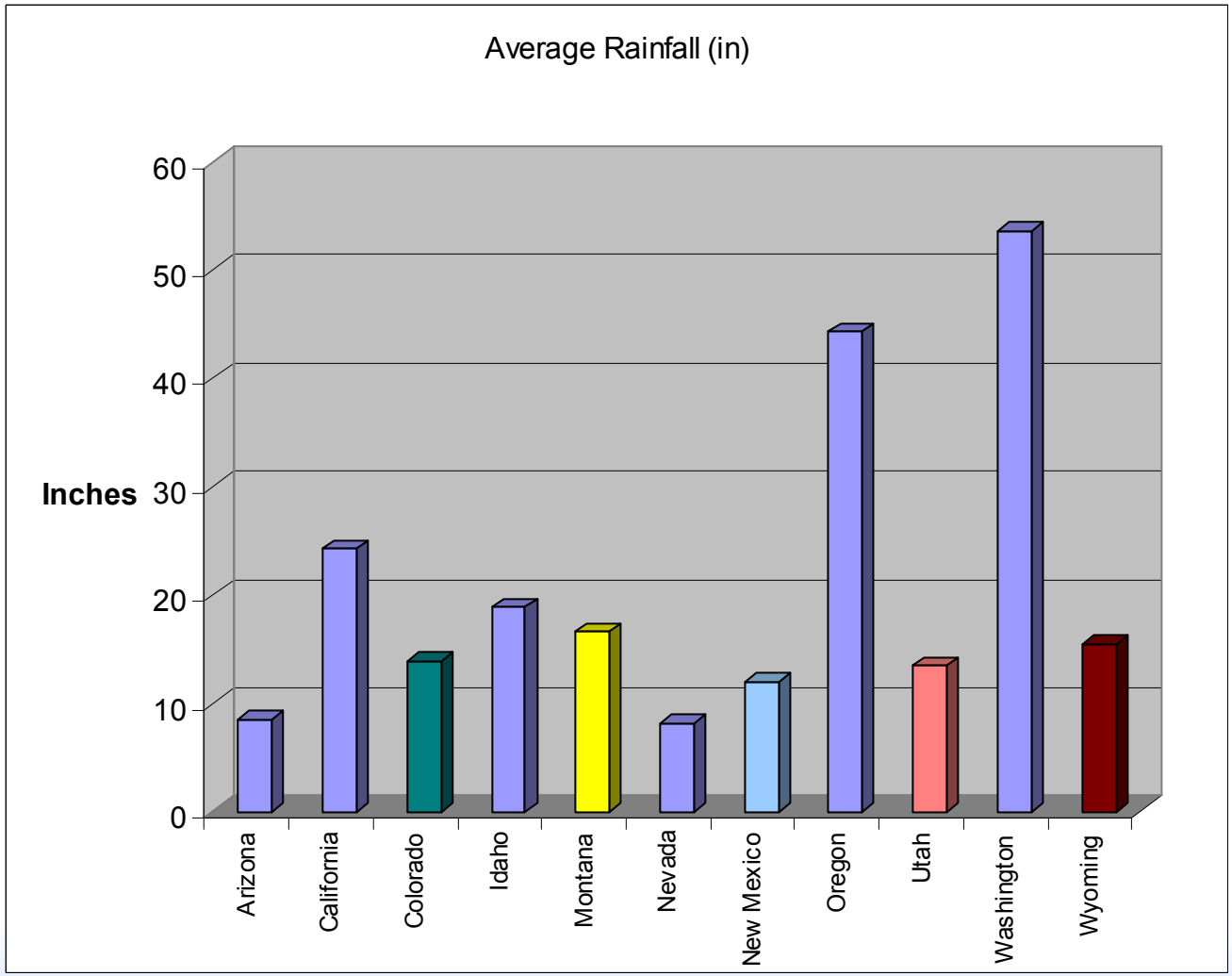
Kemmerer, Wyoming Coal-Fired PC Power Plant

Western States Average Rainfall



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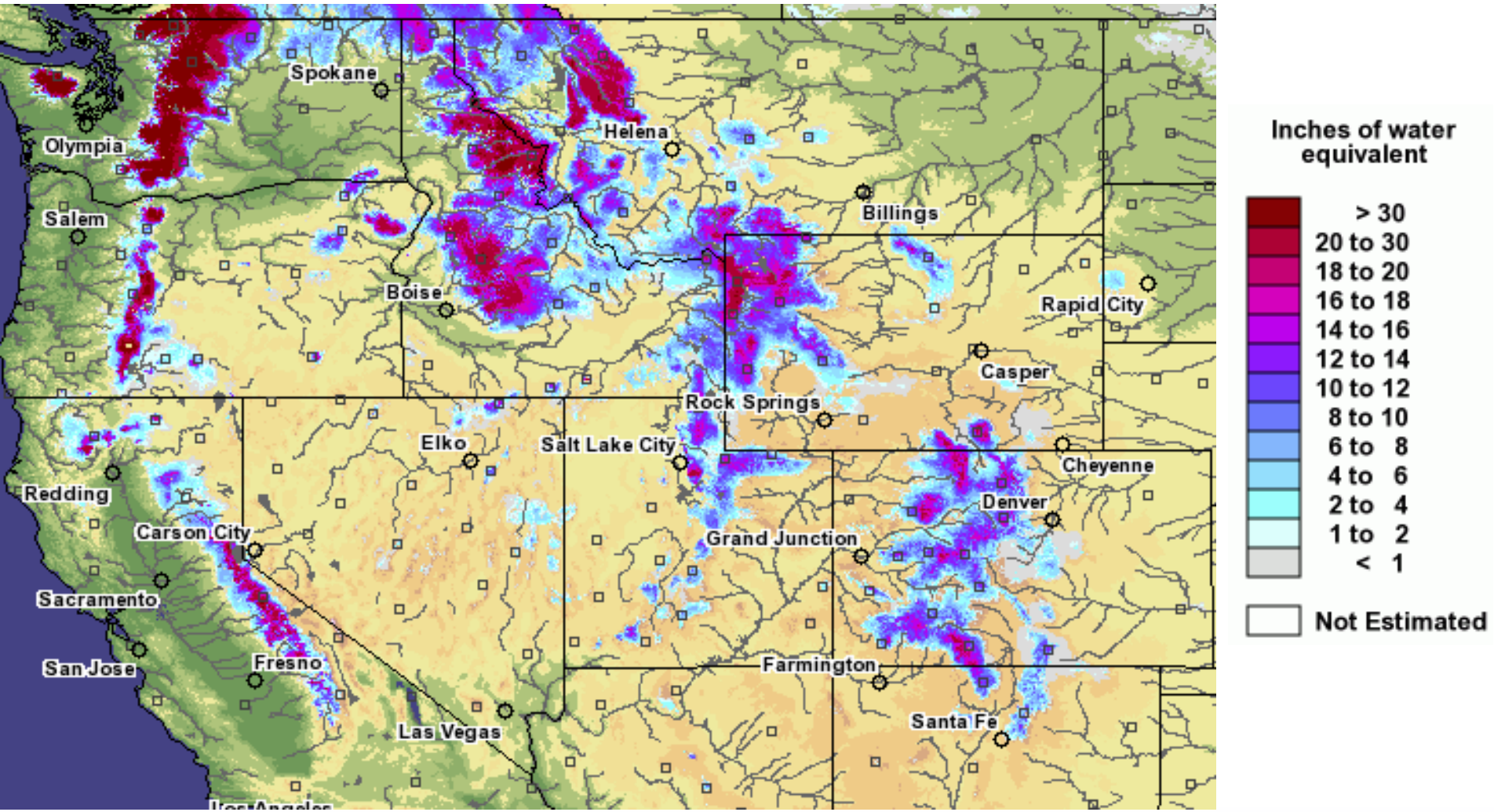
Data Source: U.S. Environmental Data Service
(average of range for all monitoring locations)

Snow Depth, March 7, 2007



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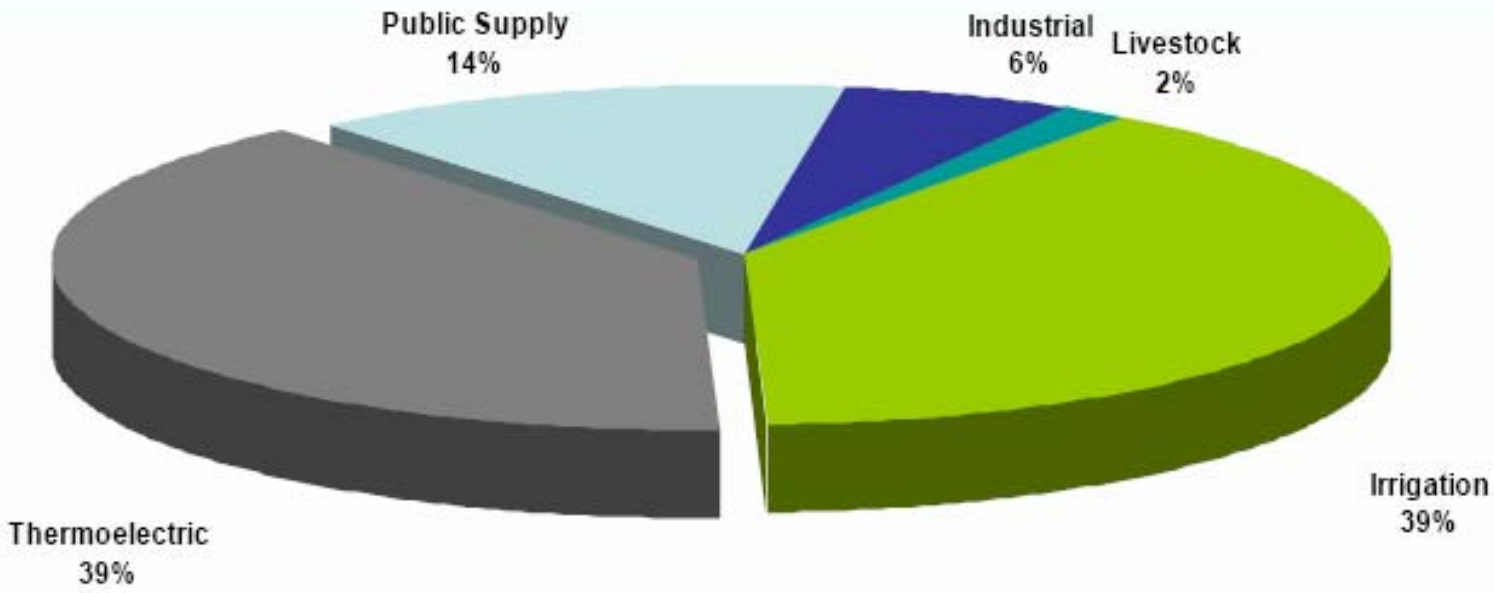
Map Source: National Weather Service
NOHRSC Data System

As Much Freshwater Is Used For Producing Electricity As For Irrigation

Estimated Freshwater Withdrawals by Sector, 2000



Source: USGS Circular 1268, March, 2004

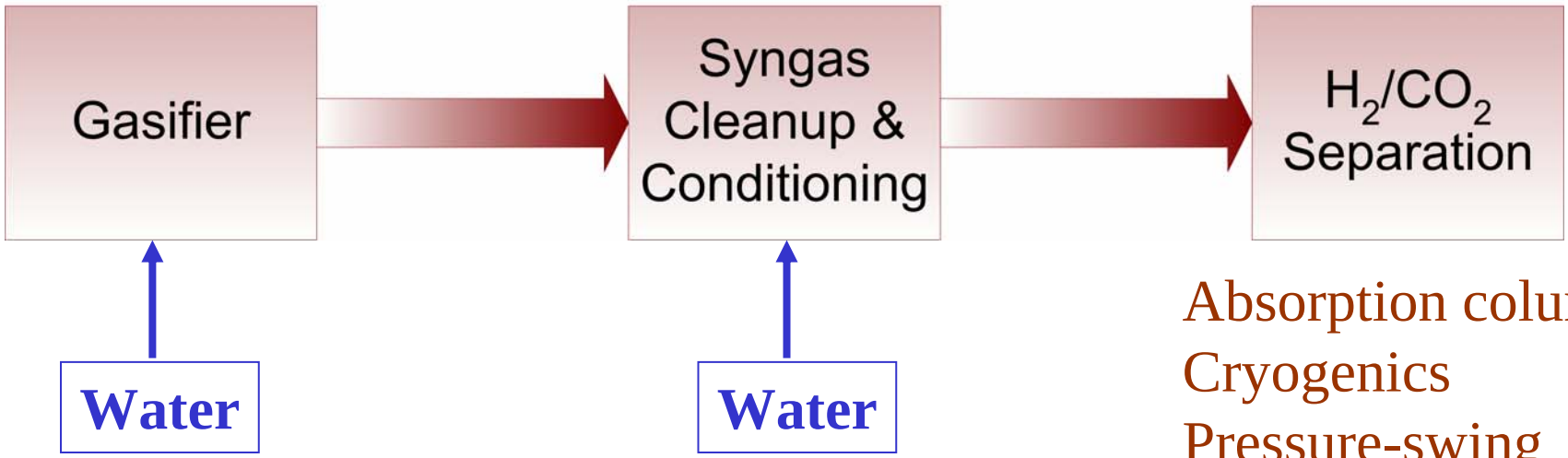

Source: NOAA

Pending Western Gasification Projects

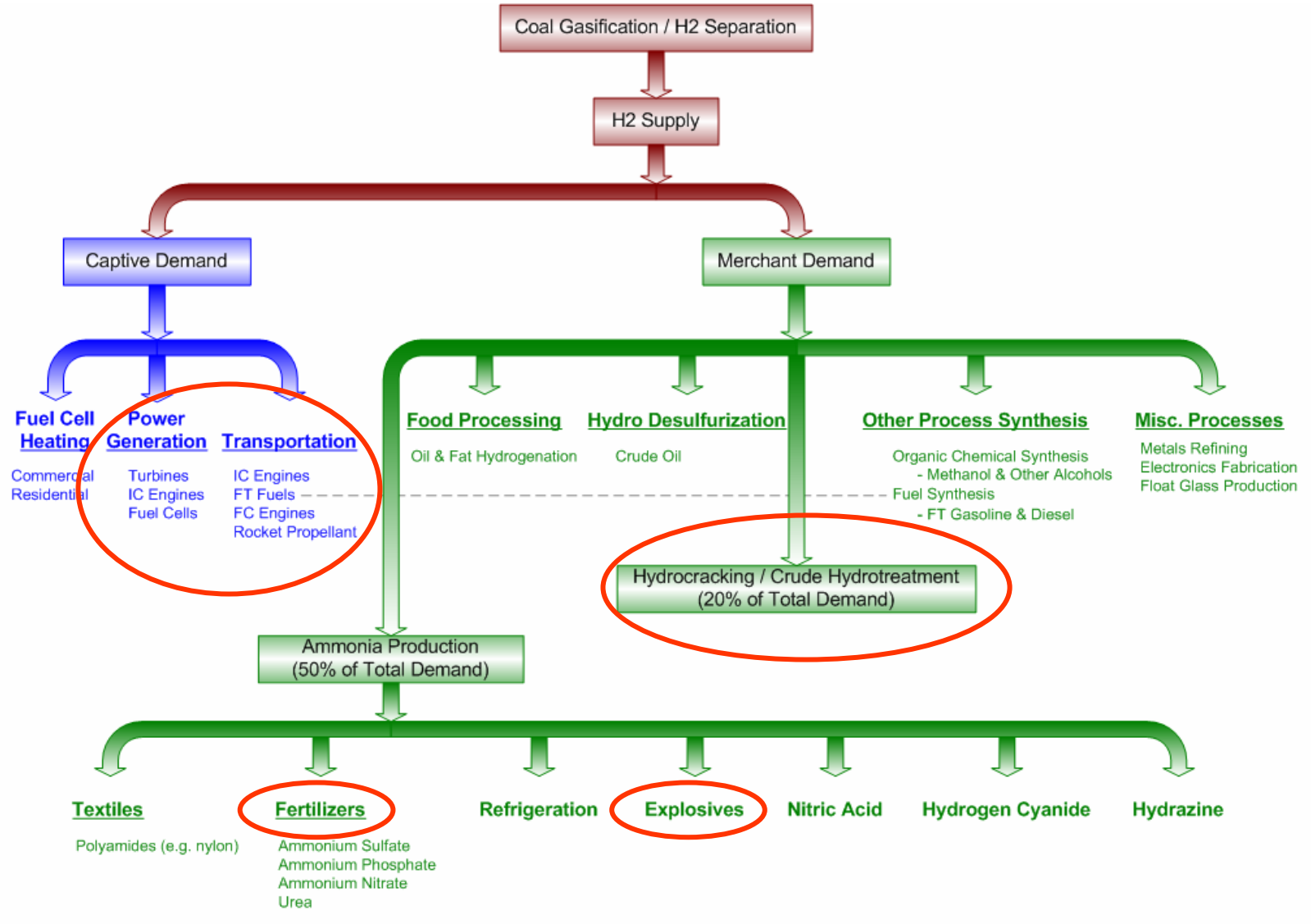
- Principally coal, some biomass
- PC power plants
- IGCC electrical power generation and PolyGen
- Hydrogen
- Ammonia or Urea
- Synthetic Fuels
  - FT diesel
  - Synthetic Natural Gas
  - Ethanol

Gasification

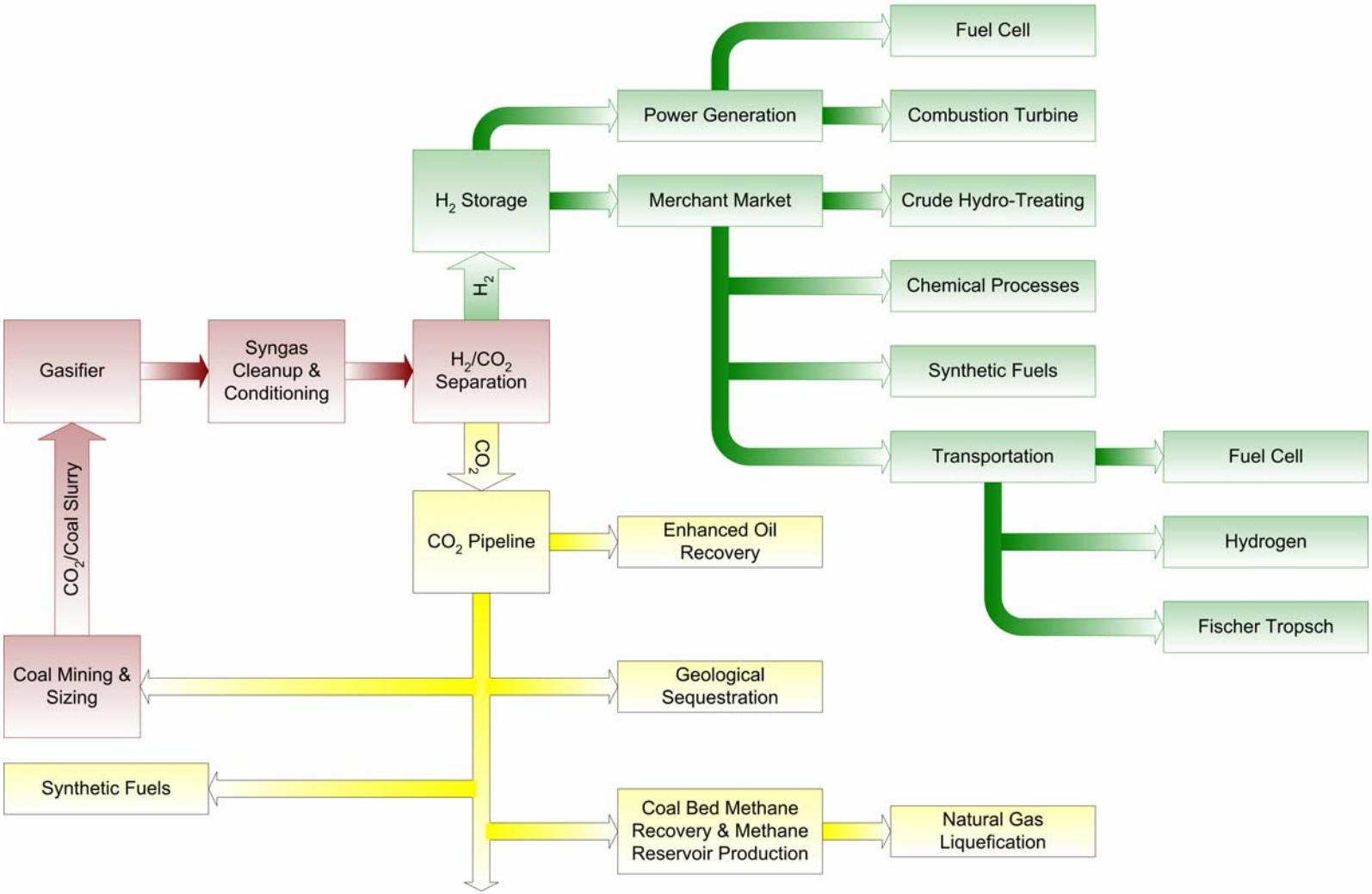
CO_2 shift and
impurities removal



Absorption column
Cryogenics
Pressure-swing adsorption
Membranes


Coal Gasification / H2 Separation
H2 Supply
Captive Demand
Merchant Demand
Fuel Cell Heating
Power Generation
Transportation
Commercial
Residential
Turbines
IC Engines
Fuel Cells
IC Engines
FT Fuels
FC Engines
Rocket Propellant
Food Processing
Oil & Fat Hydrogenation
Hydro Desulfurization
Crude Oil
Other Process Synthesis
Organic Chemical Synthesis
- Methanol & Other Alcohols
Fuel Synthesis
- FT Gasoline & Diesel
Misc. Processes
Metals Refining
Electronics Fabrication
Float Glass Production
Hydrocracking / Crude Hydrotreatment
(20% of Total Demand)
Ammonia Production
(50% of Total Demand)
Textiles
Polyamides (e.g. nylon)
Fertilizers
Ammonium Sulfate
Ammonium Phosphate
Ammonium Nitrate
Urea
Refrigeration
Explosives
Nitric Acid
Hydrogen Cyanide
Hydrazine

Carbon Utilization



CO_2 is a working and reactive fluid

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IGCC Electrical Power Generation

- California rule, “as good as NGCC”
- Requires about 60% carbon capture

Water-Gas Shift Reaction in Gasifier	High Temperature Shift Reactor	Low Temperature Shift Reactor
25% Capture	70-80% Capture	90-95% Capture

- Inherent shift in gasifier, enhanced in slurry-fed gasifier
- High temperature shift, sulfur-tolerant, upstream of sulfur removal
- Low temperature shift, downstream of gas cleanup, impurities sensitive

Western Fuels Properties Differ Markedly*

	Visbreaker Crude	*Petro. Coke*	*Pitt. #8 Bitum.*	*Illinois #6 Bitum.*	*Utah Bitum.*	*Wyoming Sub-Bit.*	*ND Lignite*
Moisture wt%	-	1.1	5.2	13	2.4	30.2	33.5
C, wt%	85.3	90.8	73.8	59.8	68.5	48.2	39.6
H, wt%	10.8	3.2	4.9	4.1	5.6	3.3	2.6
S wt%	4.0	0.8	2.13	3.7	0.49	0.37	0.5
N wt%	0.3	0.8	1.4	1.1	1.4	0.70	0.7
O, wt%	0.2	2.1	1.9	7.6	13.5	11.9	9.7
Ash, wt%	0.15	1.2	5.0	10.7	8.3	5.3	15.9
HHV – AR (BTU/lb)	13,500	12,150	13,260	10,982	12,700	8,340	6,010
H:C Ratio	1.52	0.42	0.80	0.82	0.97	0.82	0.79

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* Data Sources:
Argonne Premium Coal Samples Bank, U.S. Bureau of Mines

Hydrogen Makeup with Water

Product	Hydrogen	FT Fuels	SNG	Urea
H:C ratio required	2 char gasification and shift reaction	4 (C_8H_{16}) plus produced water	4 (CH_4)	4 $(NH_2)_2CO$

Reforming and CO shift

$CH_4 + H_2O \rightarrow CO + 3H_2$

$CO + H_2O \rightarrow CO_2 + H_2$

Gasification of char

$C + H_2O \rightarrow CO + H_2$

COS Hydrolysis reactor

$COS + H_2O \rightarrow CO_2 + H_2S$

Synthetic Fuel

$(X)CO + (3X)H_2 \rightarrow C_XH_{x*2} + (X)H_2O$ (F-T fuel)

$CO + 3H_2 \rightarrow CH_4 + H_2O$ (methanation)

Ammonia and Urea

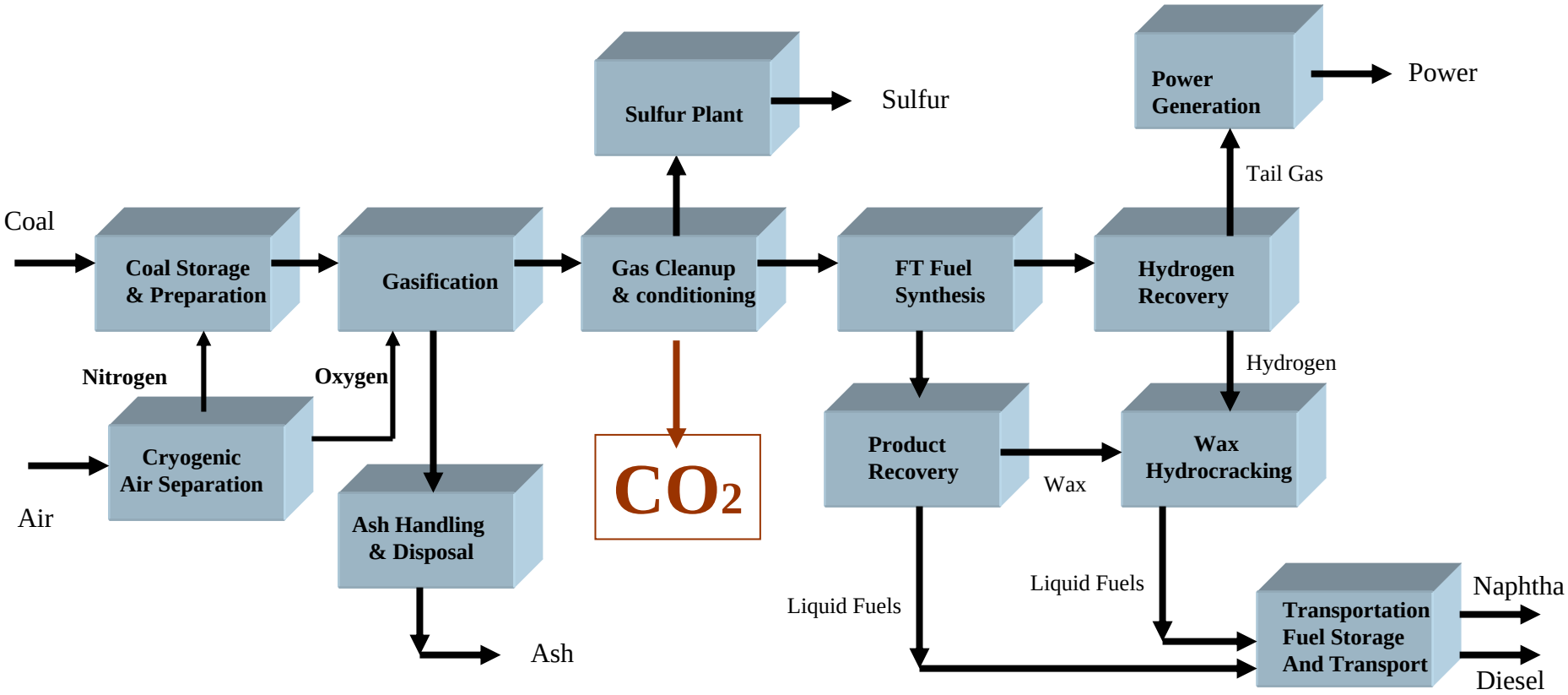
$N_2 + 3H_2 \rightarrow 2NH_3$

$N_2 + 3H_2 + CO_2 \rightarrow (NH_2)_2CO + H_2O$

Ethanol

$2CO + 4H_2 \rightarrow C_2H_6O + H_2O$

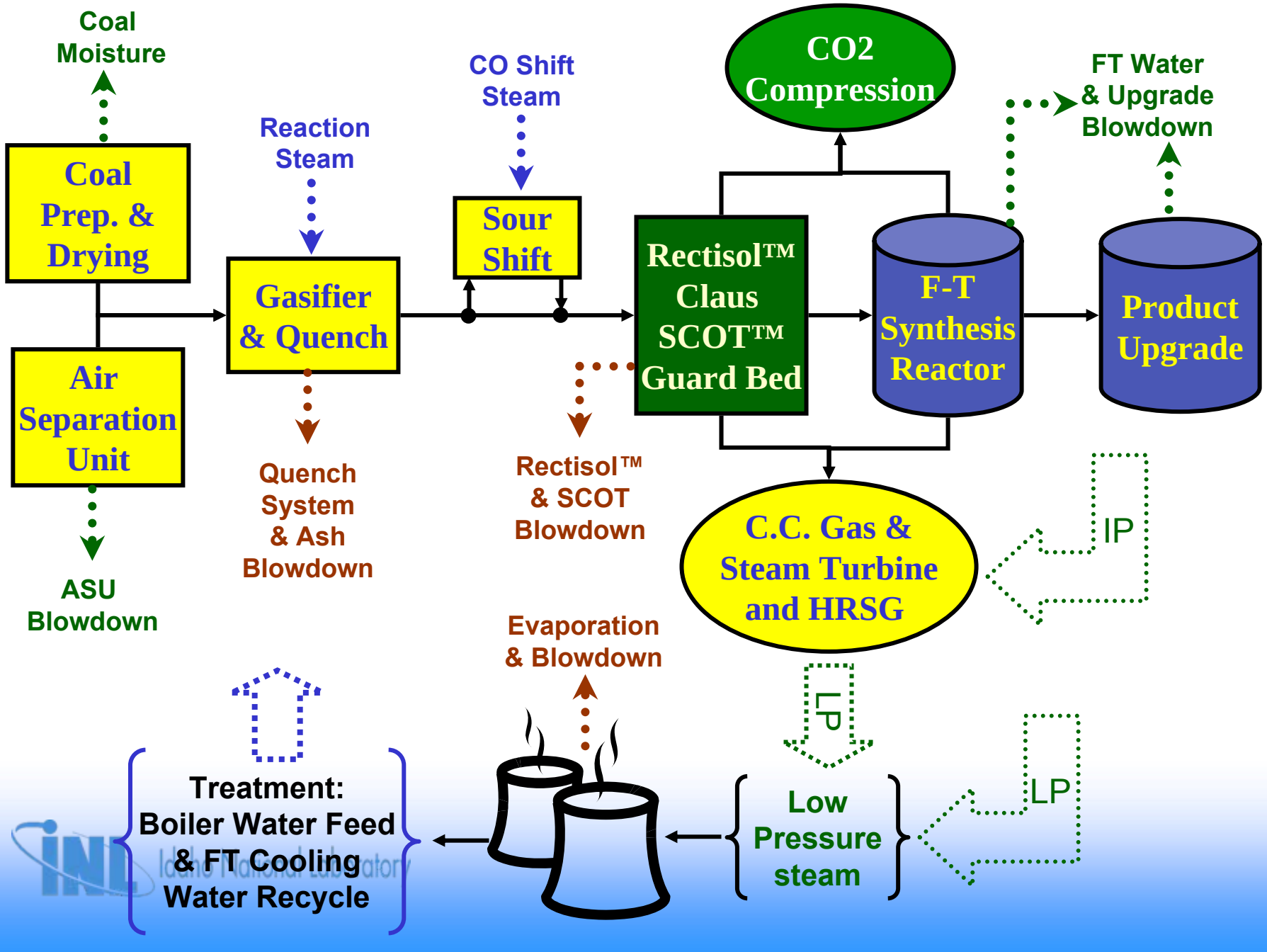
Liquid Synthetic Fuels Process



50% of carbon is captured and is sequestration ready

F-T Plant Water Balance

- 10,000 bpd total liquids (naphtha and diesel)
- Low moisture bituminous; Col., Utah, N.M.
- High moisture sub-bituminous, Wyo., or Mont.
- Dry-feed gasifier
- Conventional cooling tower for LP steam condensation
- CO_2 compression for 80% carbon utilization approach
    - 50% sequestered
    - 30% in FT fuel


Coal Moisture
Coal Prep. & Drying
Air Separation Unit
ASU Blowdown
Reaction Steam
Gasifier & Quench
Quench System & Ash Blowdown
CO Shift Steam
Sour Shift
Rectisol™ & SCOT Blowdown
Rectisol™ Claus SCOT™ Guard Bed
CO2 Compression
F-T Synthesis Reactor
FT Water & Upgrade Blowdown
Product Upgrade
C.C. Gas & Steam Turbine and HRSG
IP
LP
LP
Low Pressure steam
Evaporation & Blowdown
Treatment: Boiler Water Feed & FT Cooling Water Recycle

Assumptions

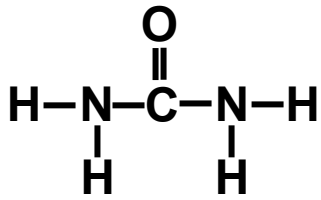
- Quench System and Ash Water Blowdown are disposed
- Rectisol™ and SCOT Blowdown are disposed
- Coal Moisture, ASU Blowdown, FT Product Water, and Product Upgrade Blowdown are treated and used for Gasification and CO Shift
- BFW is treated to reduce Cooling Tower Blowdown
- Heat integration between gasification, FT, and product upgrade

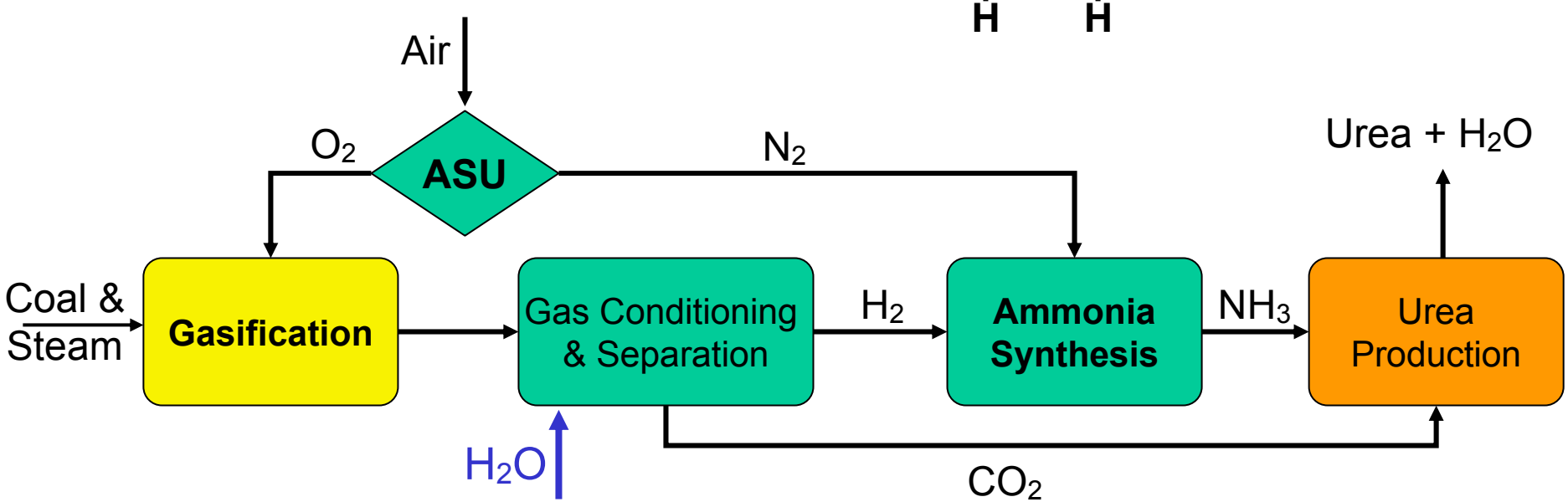
Water Balance Summary

Stream(s)	Bituminous	Sub-Bituminous
Wet Coal Feed Rate (tpd)	4870	6276
Dry Coal Feed Rate (tpd)	4672	4582
Coal Moisture (MM gpd)	0.049	0.42
Gasifier and CO Shift Steam Duty (MM gpd)	1.31	1.32
Quench System and Ash Blowdown (MM gpd)	0.52	0.67
Rectisol, SCOT Blowdown (MM gpd)	0.03	0.01
ASU, FT and Upgrade Output (MM gpd)	0.52	0.51
CO Shift Reactor Makeup (MM gpd)	0.79	0.38
Cooling Tower Makeup (MM gpd)	5.28	4.68
Net Water Requirements (MM gpd)	6.07	5.06
Waste Water Discharge (MM gpd)	0.56	0.68
Barrels Water Consumed/Barrel FT Liquid	14.5	12.0

tpd = tons per day
MM gpd = 1 million gallons
barrel = 42 gallons

Urea Production





$3H_2 + N_2 \rightarrow 2NH_3$

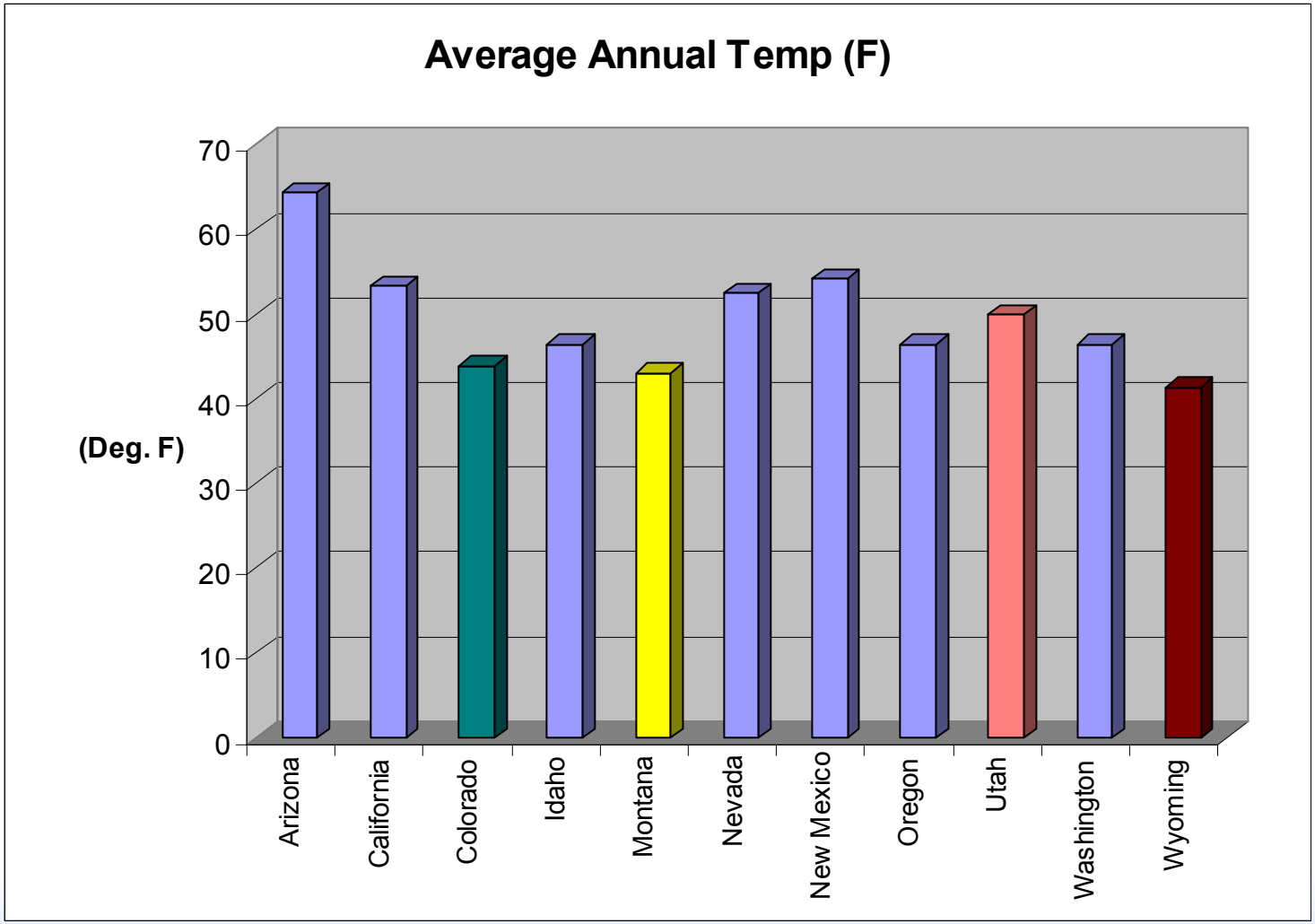
$3H_2 + N_2 + CO_2NH_3 + CO_2 \rightarrow H_2N\text{-}COONH_4$ (ammonium carbamate)

$H_2N\text{-}COONH_4 \rightarrow (NH_2)_2CO + H_2O$

Water Conservation Alternatives

- Steam-to-air heat gas coolers, cooling towers
- Replace cooling tower with closed-loop, cascading refrigeration / heat recovery / power generation
  - Large heat exchangers
  - Ammonia, propane, refrigerant systems proposed
- Condensing steam turbines
- Reclaim and treat coal-bed methane and oil well produced water

Western States Average Temperature



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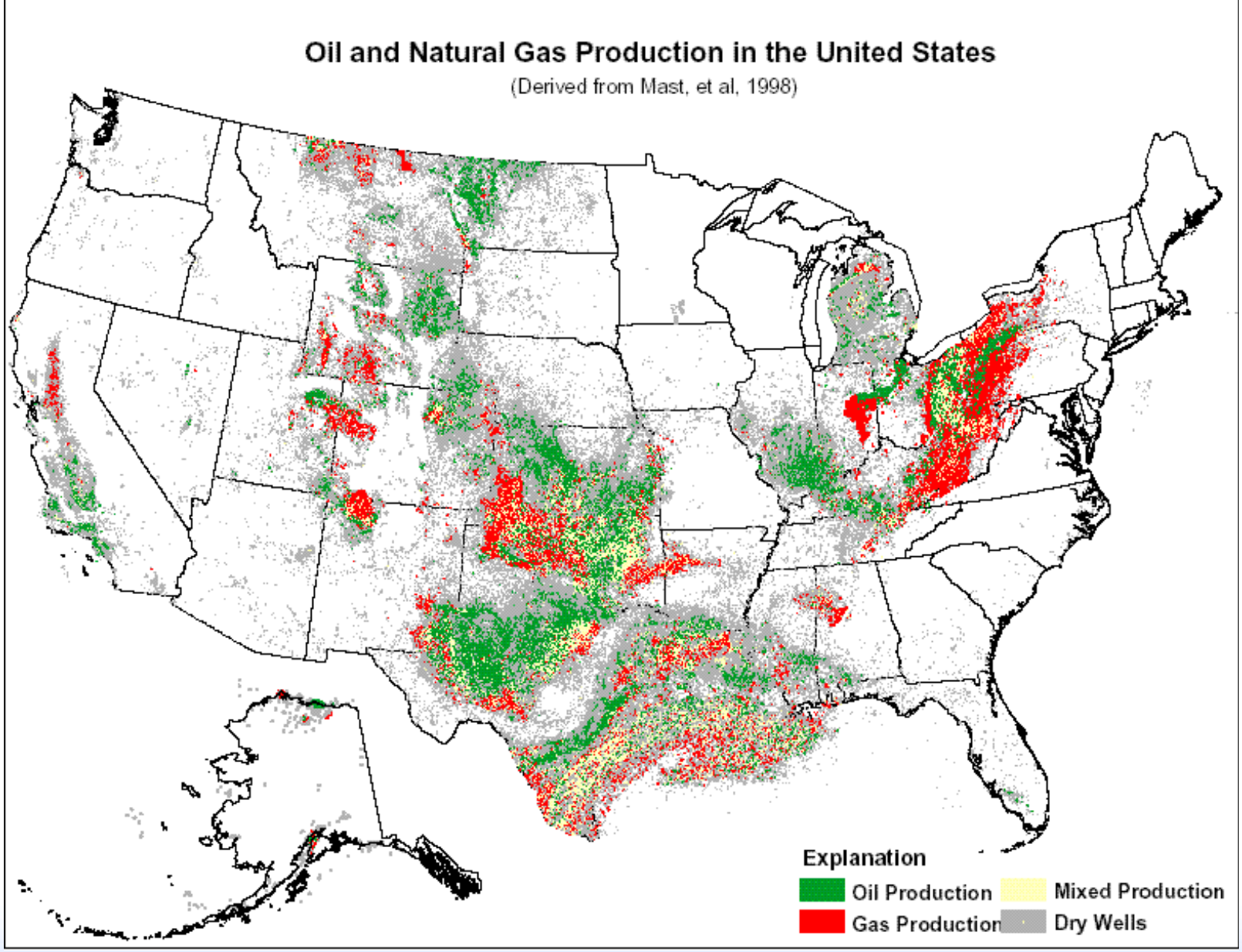
Data Source: U.S. Environmental Data Service
(sorted for probable plant locations)



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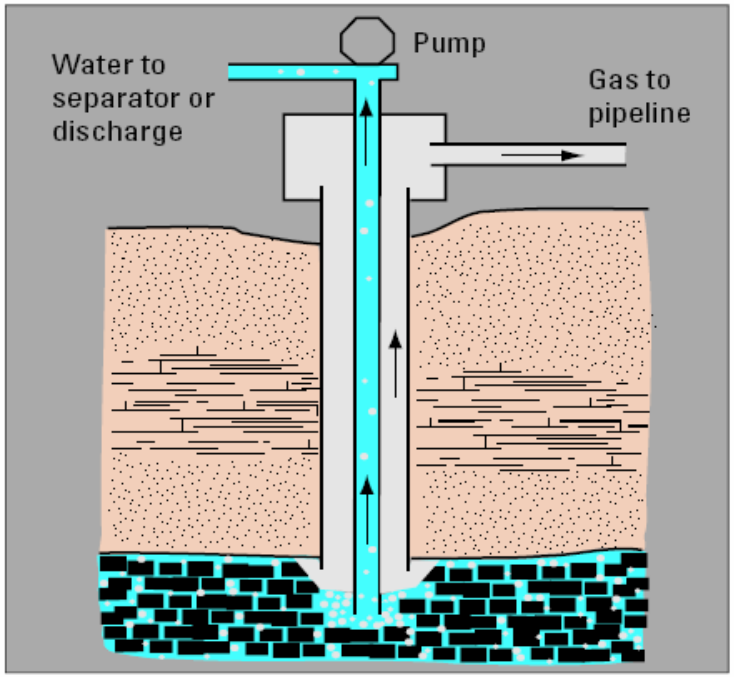
Source: U.S. Geological Survey



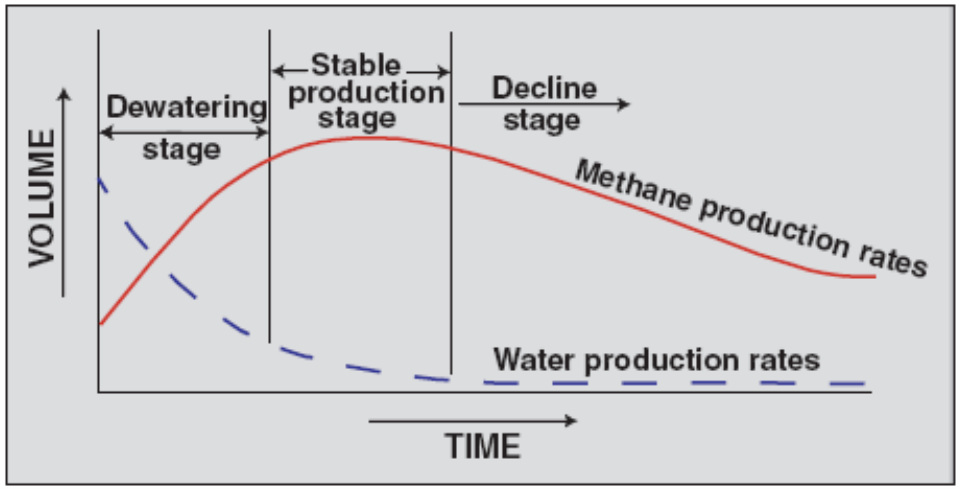
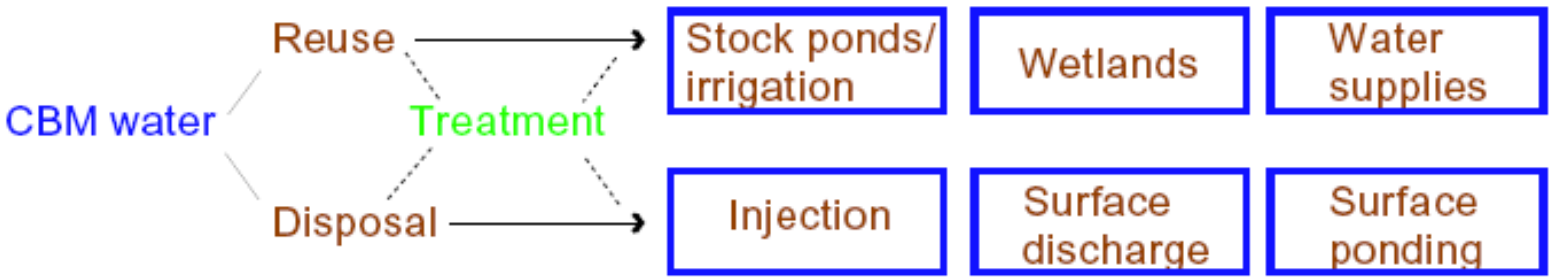


Figure 2. Typical production curves for a coal-bed methane well showing relative volumes of methane and water through time. Modified from Kuuskraa and Brandenberg (1989).



Source: U.S. Geological Survey

Wyoming Coal Bed Natural Gas*

- 23,750 CBM wells drilled by end of 2006
- 2006 CBM from PRB
  - 950 million cubic feet natural gas per day
  - 1.5 million barrels of water per day
- 1.85 barrels of water per thousand cubic feet gas
- WOGCC currently estimates total gas recovery to be 8 trillion cubic feet with 15 billion barrels of water
- Equivalent demand for 100,000 barrels/day FT fuels for 34 years
- Water quality varies significantly across coal seams

* Wyoming Oil and Gas Commission
CBNG Task Force Meeting, May 4, 2006