Oregon
Sustainable Energy, LLC

GUANIDINE

Safe, Clean & Flexible

Albert Einstein

"The significant problems we face today cannot be solved at the same level of thinking we were at when we created them"

Properties of an Ideal Fuel

- *High Energy-Density*
- *Safe to Handle*
- *Practical to Store & Distribute*
- *Clean & Non-polluting*
- *Flexible*

Best Energy Sources

- *Often not near grid*
  - Wind, Solar, Water, BioMass
- *Transmission Losses*
  - Long distances

Ammonia Needs:

A More

Safe *and* ***Practical***

Means of

Storage and Distribution

Ammonia is:

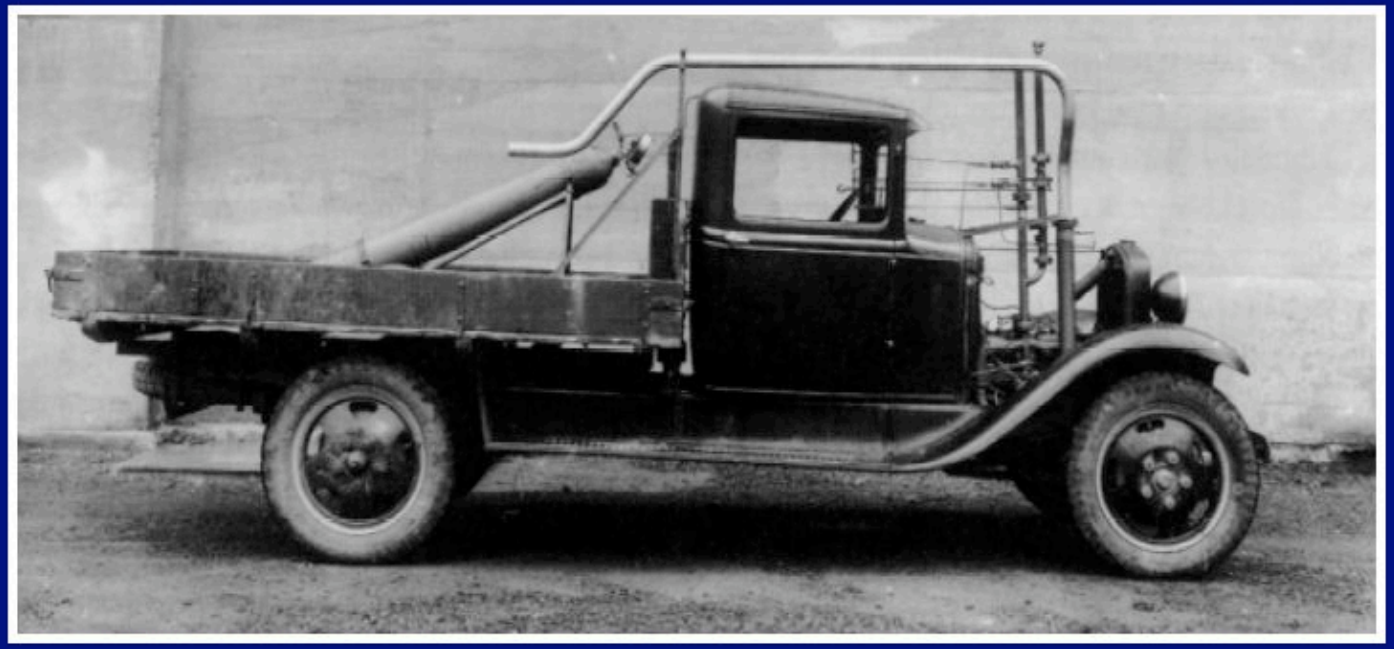
- *An Excellent Fuel*
  - High Specific Energy
  - High Octane
  - ICE Usage Easy
- *No Carbon-based Emissions*
- *A Hydrogen Carrier ?*

Ammonia: *Fuel History*

- Rudolf Diesel - 1895
  - *Diesel engine*
- Norsk Hydro - 1934
  - *Hydroelectric ammonia*
- Belgium – WW II
  - *Ammonia-fueled buses*
- US Army - 1960
  - *Ammonia- nuclear reactors*

Ammonia Vehicle - 1933

Ammonia fuelled car, Rjukan 1933



Source : "Worth a try"
Research and Development in Norsk Hydro through 90 years",
Oslo 1997 (page 125)

But Ammonia is:

- *Toxic and Corrosive*
  - Expensive and Dangerous
- *Distribution*
  - Limited - only in U.S.
- *Fertilizer Usage - Risks*
  - Only in the U.S.
- *Ammonia Plants*
  - Urea Nearly Always (Gosnell – KBR)

Major Obstacles to Use

- *Safety and Handling*
- *Storage and Distribution*

A Possible Solution?

Guanidine

Safe

- A Solid material
  - *Melting Point* 122° F
- Non-explosive
- Low toxicity
- Low flammability

Clean

- Fresh Water Electrolysis
  - *CO_2 neutral*
  - *CO_2 - captures 1 and releases 1*
- Salt Water Electrolysis
  - *For each ton of Guanidine*
  - *Captures 4.4 tons of CO_2*
  - *Sequesters 3.4 tons of CO_2*

Flexible

- Storage and Distribution
  - *Existing systems*
- A Pure Fuel
  - *Solid or liquid*
  - *High energy density*
- Blended
  - *Soluble in water or ethanol*
  - *G11 – replace gasoline in E85*

Some Advantages

- Specific Energy
  - *3.58 kWhr/kg*

    2015 FreedomCar Target - 3.0 kWhr/kg
- Effective Energy Density
  - *4.7 kWhr/L*
  - *Ammonia - 3.5 kWhr/L*
- Urea Eutectic Mixture
  - *Easy to Handle*
  - *Low M.P. ~30° C*

Guanidine: History

- 1861
  - *Chemistry published*
- 1866
  - *Hydrolysis demonstrated*
- 1931
  - *German patent*
- 1950
  - *American Cyanamid Co*
- 1963
  - *Monsanto patent*

Guanidine: *A Fuel*

Synthesis

Water Electrolysis

Coal

Natural Gas (90%)

⇒ Ammonia ⇒ Urea ⇒ Guanidine

CO_2 Capture: Fresh water - 1
Salt water - 3.4

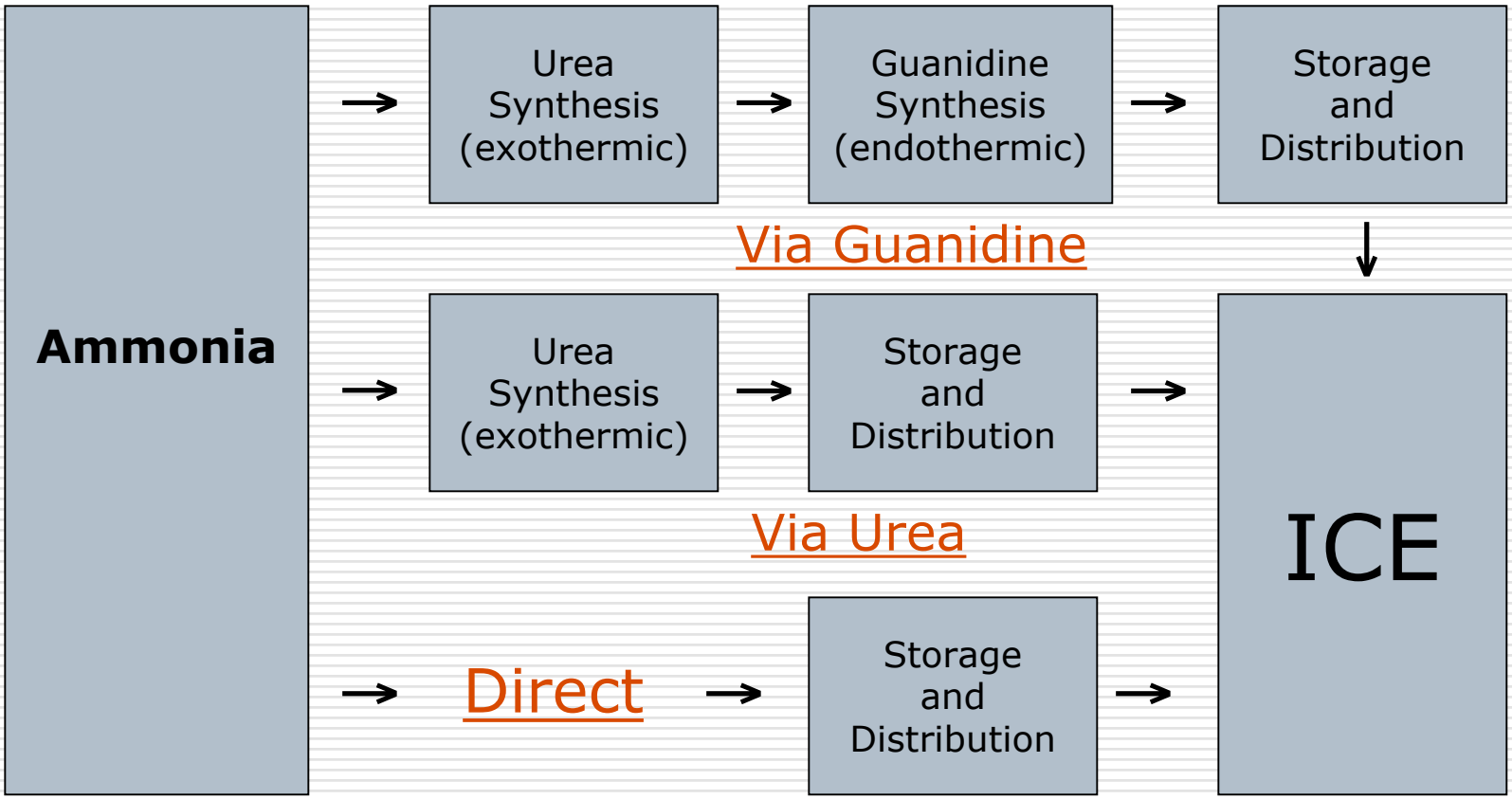
Combustion

Guanidine + Water

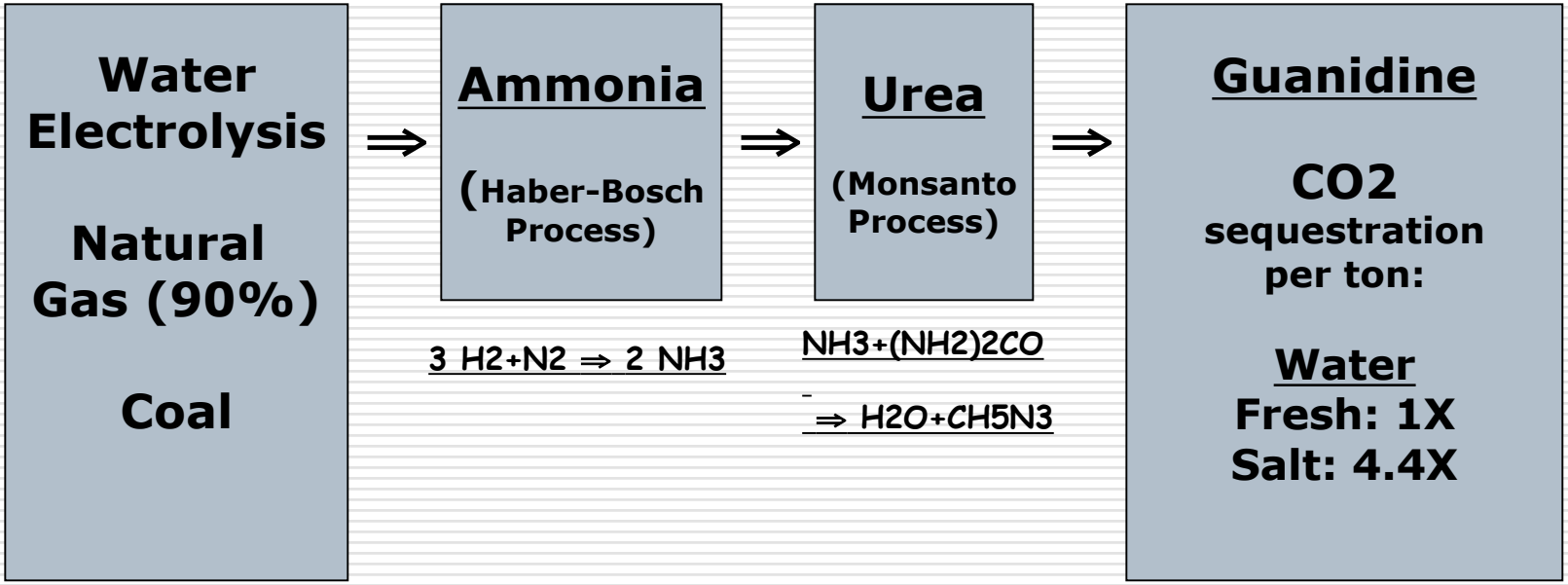
⇒ Ammonia ⇒ Burns to form Nitrogen + Water

Emits 1 CO_2

Ammonia Fuel Paths



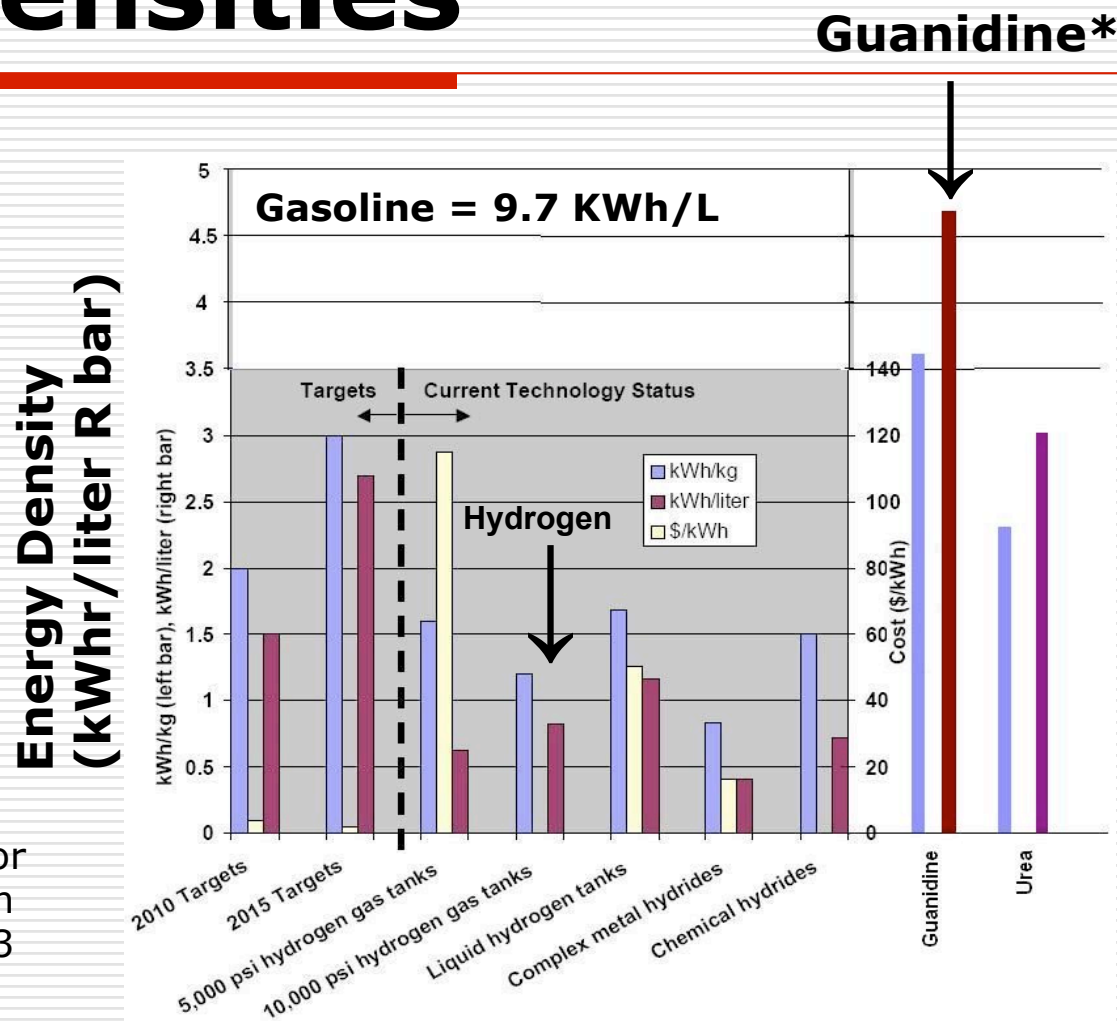
Guanidine Synthesis



Energy Densities

Guanidine has over 6X the energy density of hydrogen stored in 10,000 psi gas tanks.
*Assumes using waste heat and exhaust water

From:
J. Milliken, Grand Challenge for Basic and Applied Research in Hydrogen Storage, June 2003



Fuel Comparison

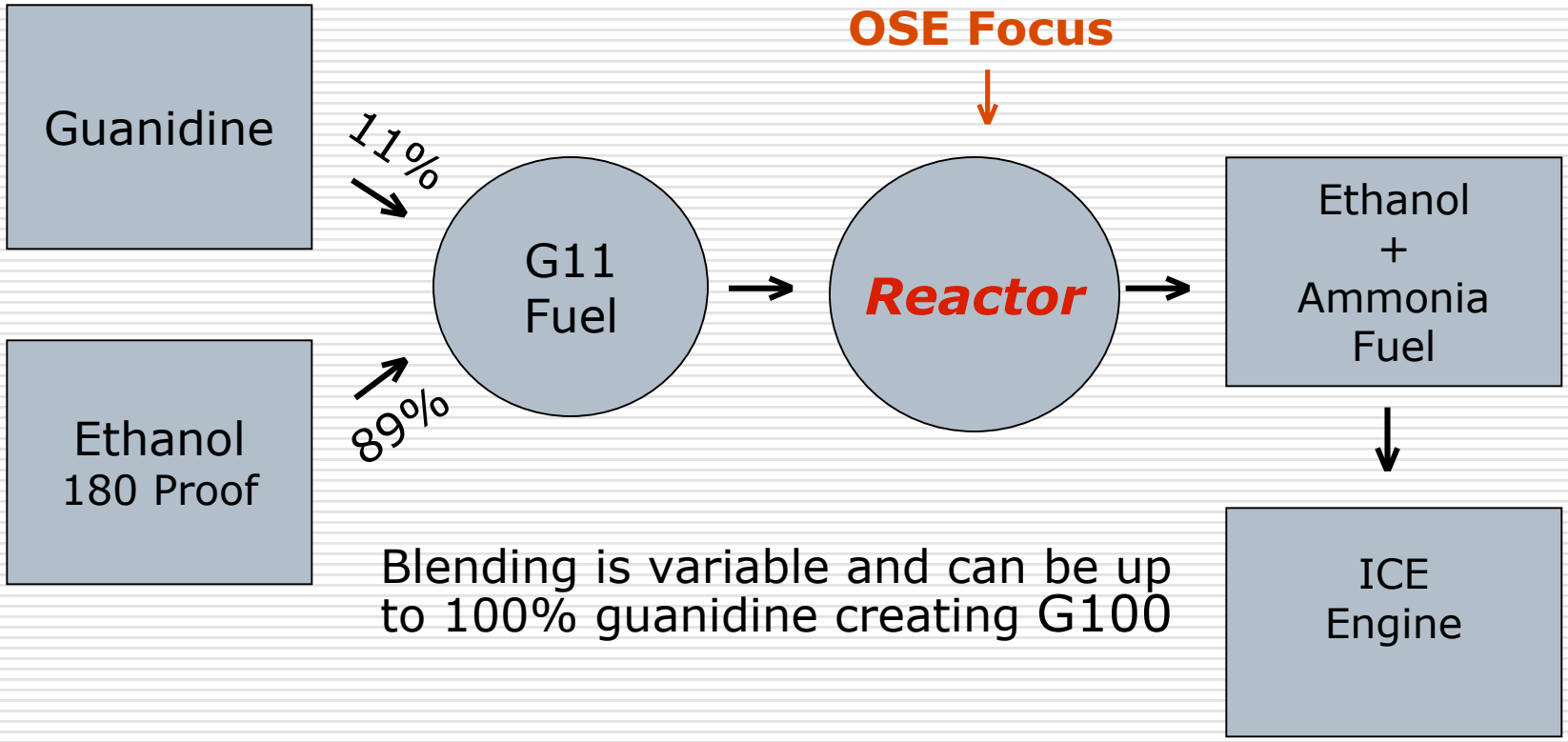
Property	***Guanidine***	***Urea***	***Ammonia***	***Hydrogen***
Energy Density	4.7 kWhr/L	3.0 kWhr/L	3.5 kWhr/L	0.8 kWhr/L @ 10,000 psi
Specific Energy	3.58 kWhr/kg	2.35 kWhr/kg	5.2 kWhr/kg	1.2 kWhr/kg
H:C Ratio*	9:1	6:1		
Safety	Good	Excellent	Poor	Poor
Storage	Solid (MP 50C)	Solid	Gas (~10 bar)	Gas (5-10 K psi)
Distribution	Easy	Easy	Difficult	Expensive
Water Solubility	Infinite	.05 kg/l		
Ethanol Solubility	Infinite	1 kg/l		
Toxicity	Low	Low	High	None

2015 FreedomCar Target

3.0 kWhr/kg

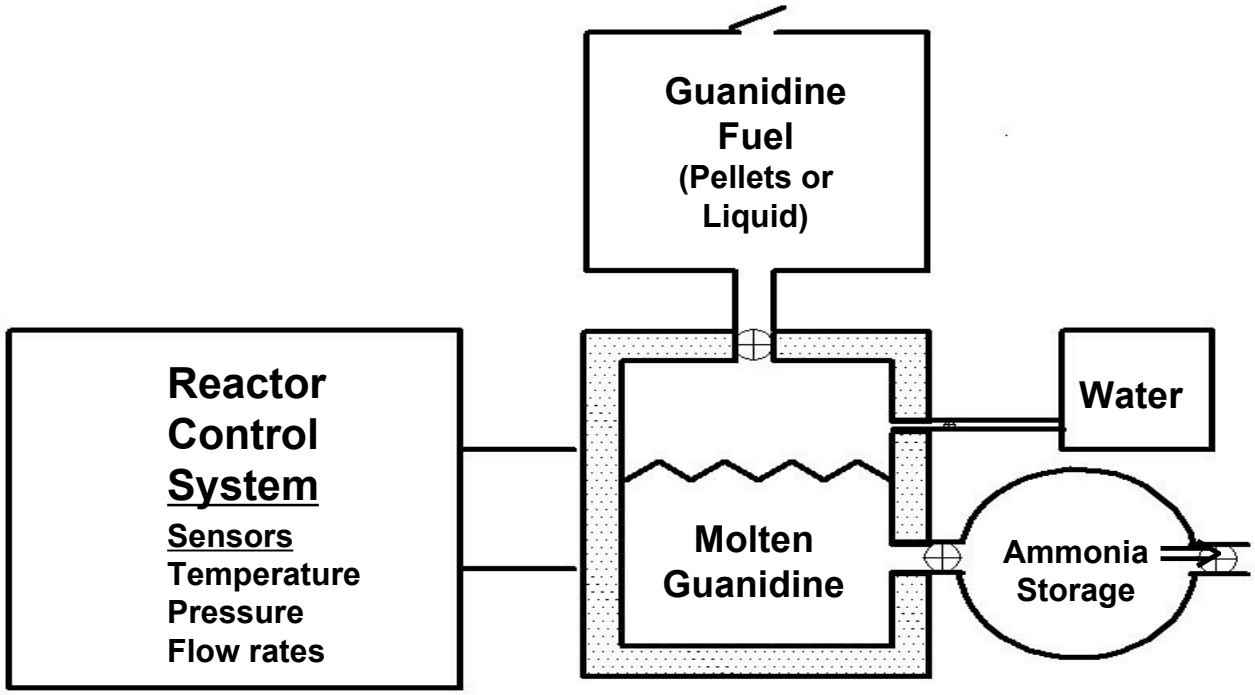
* When burned

The G11 Fuel System



Blending is variable and can be up to 100% guanidine creating G100

G-Reactor™



Running: Captures engine heat and exhaust water

Starting: Utilizes ammonia or cracked ammonia from storage until reaching operating temperature

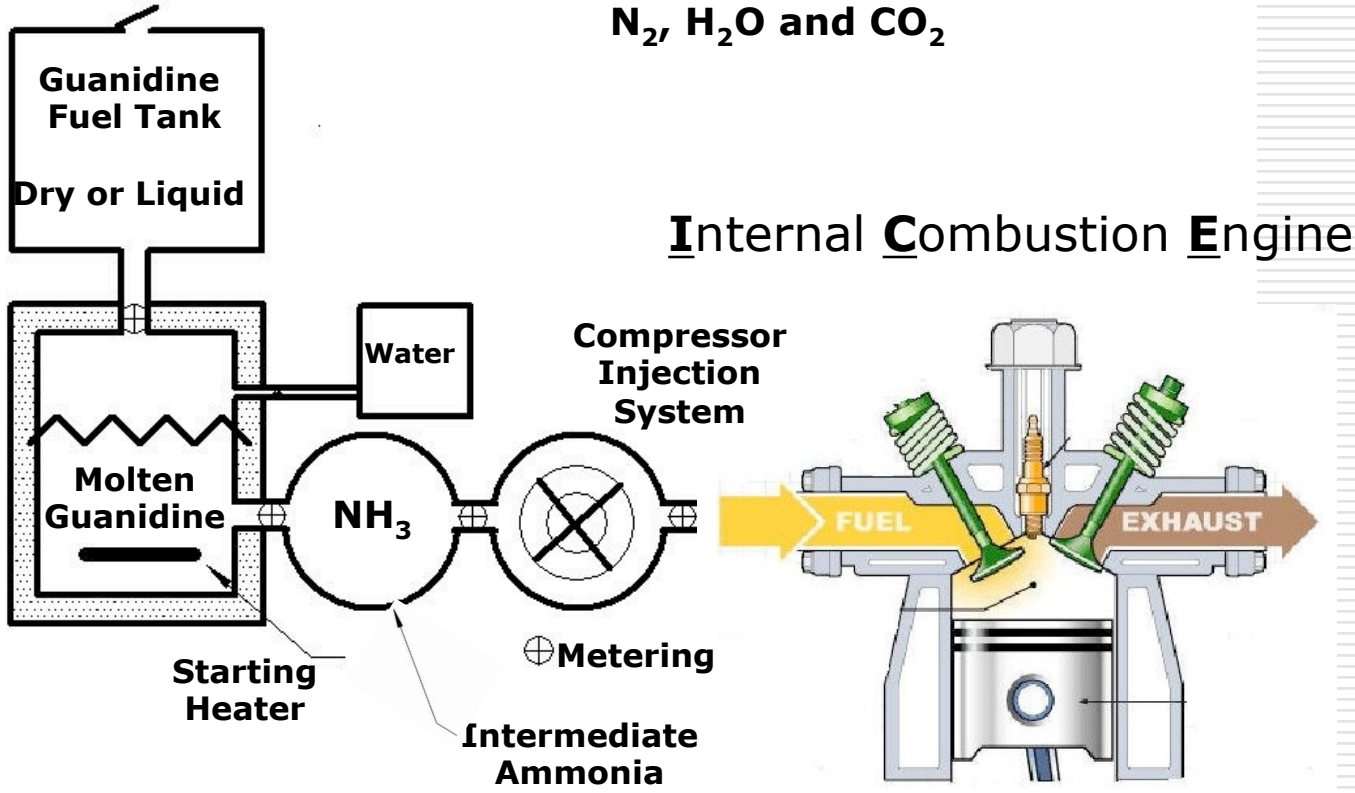
To **ICE**

Guanidine: *An ICE*

Diesel or Spark Ignition

Exhaust Emission
N_2, H_2O and CO_2

Internal Combustion Engine



Running: Utilizes engine heat and exhaust water

Starting: Utilize E85 fuel until reach operating temperature

Development Program

- **Phase I**
  - *Guanidine Chemistry & Catalysts*
  - *Laboratory MicroChannel Reactor*
  - *Oregon Graduate Institute*
  - *DOE/ORNL Work For Others*
- **Next Phases**
  - *Prototypes*
  - *Build the Company*
  - *Strategic Partnering*