# The Best Fuel by Mass Loses on Both Volume and Mass Once the Container Is Counted

— Hydrogen gives **120** MJ/kg against gasoline's **44** MJ/kg, a factor of **2.727273** — the separator is whether one counts the contents alone or the container with them — [Paper 816]

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— *From thinking to syncing.* —

**Abstract**

**Hydrogen is often cited as the fuel with the highest energy per unit mass.This paper counts the same two fuels with the contents alone and with the container included, and sees how the ranking changes.No new theorem or law is claimed. First, by the contents alone hydrogen wins——120 MJ/kg against 44 MJ/kg, a factor of 2.727273** (Section 2). **Second, a gas does not pack under pressure——at 300 K and 700 bar an ideal gas would give 56.579264 kg/m³, but with a compressibility factor of 1.40 it is 40.413760 kg/m³** (Section 2). **Third, by volume it loses——4.849651 GJ/m³ at 700 bar, one 6.804613th of gasoline's 33.000000 GJ/m³, and one 3.884181th even as a liquid** (Section 3). **Fourth, and this is the core. With the container counted it loses by mass as well——a hydrogen fraction of 0.057 gives 6.840000 MJ/kg of system against gasoline's 41.800000 MJ/kg (fraction 0.95), one 6.111111th** (Section 4). **Fifth, the direction reverses because the container does not scale with the contents——a win by 2.727273 becomes a loss by 6.111111** (Section 4). **Sixth, the separator is whether one counts the contents alone or the container with them ——"hydrogen is the lightest source of energy" is undecided until one says what is inside the count** (Section 5).

**Keywords**: hydrogen storage, heating value, compressibility factor, energy per volume, container mass, representative values.

**Scope of this paper (scope note)**: **No new theorem or law is claimed——the heating values of hydrogen and gasoline, the compressibility of a gas at high pressure, the density of liquid hydrogen, and storage fractions including the container are all known.The values are representative——the compressibility factor 1.40, the hydrogen fraction 0.057, the gasoline fraction 0.95 and the liquid density 70.8 kg/m³ vary from system to system.No real tank is assessed——the merits of particular products or materials are not treated.Efficiency is not included——the fraction of the heat that a fuel cell or an engine can turn into work is not entered; only heating values are counted.The surroundings are not treated——filling, boil-off, safety and cost of production are not the subject.Relation to earlier papers**: **Paper 730 showed that the first layer of clothing and the second are worth different amounts, because a resistance one cannot take off sits in the denominator——this paper stands beside it: there a denominator in a sum, here a container that does not scale with the contents, both cases where counting the system changes the ranking.Paper 326 showed that the square-cube "law" is an identity, not a law——here too what moves the ratio is not physics but what is put in the denominator.**What is added is **setting the same two fuels side by side under three ways of counting**, **counting the drop of the density to 40.413760 kg/m³ once compressibility is included**, **measuring how a win by 2.727273 becomes a loss by 6.111111**, and **placing the separator on contents alone versus container included**.

## 1. Notation and the Question

**Setting**: **a fuel is counted three ways: by heating value per mass of contents, per volume of contents, and per mass of the system including its container.**

**Hydrogen is taken at 120 MJ/kg and gasoline at 44 MJ/kg with 750 kg/m³.The density of compressed hydrogen is the ideal-gas value divided by a compressibility factor $Z$.**

$$\rho = \frac{P\,M}{Z\,R\,T}, \qquad M = 0.002016\ \mathrm{kg/mol}, \qquad T = 300\ \mathrm{K}$$

**Question**: **how does the ranking change with the way of counting?**

## 2. Mass of Contents, and the Density of a Gas

**Computation 2.1**: **densities were computed at two pressures.**

| pressure (300 K) | ideal gas (kg/m³) | with $Z = 1.40$ (kg/m³) |
|---|---|---|
| 350 bar | 28.289632 | 20.206880 |
| 700 bar | 56.579264 | 40.413760 |

> **Observation 2.2**
>
> **by contents alone hydrogen wins, and a gas does not pack under pressure.It wins by 2.727273 per mass, yet even at 700 bar the density is 40.413760 kg/m³, less than a twenty-fifth of water——doubling the pressure does double the density (2.000000), but the starting point is too light.**

## 3. Counting by Volume

**Computation 3.1**: **heating value per volume was listed.**

| form | per volume (GJ/m³) | against gasoline |
|---|---|---|
| hydrogen at 700 bar | 4.849651 | one 6.804613th |
| hydrogen as liquid (20 K) | 8.496000 | one 3.884181th |
| gasoline | 33.000000 | 1 |

> **Observation 3.2**
>
> **by volume it loses.One 6.804613th at 700 bar, and one 3.884181th even as a liquid——the factor 2.727273 per mass is swallowed by the difference in density.**

## 4. Counting the Container

**Computation 4.1**: **the count was redone per mass of the system including the container.**

| fuel | fuel fraction of the system | per system mass (MJ/kg) |
|---|---|---|
| hydrogen (high-pressure vessel) | 0.057 | 6.840000 |
| gasoline (fuel tank) | 0.95 | 41.800000 |

> **Observation 4.2**
>
> **this is the core. With the container counted it loses by mass as well.6.840000 against 41.800000 MJ/kg is one 6.111111th, reversing the win of 2.727273 counted by contents alone——the container's mass does not scale with the contents, so the fraction itself decides the ranking.**

**Computation 4.3**: **the volume of contents needed to carry 5 kg of hydrogen was computed.**

| form | volume of contents |
|---|---|
| **700** bar | **123.7** L |
| liquid (**20** K) | **70.6** L |
| the same energy as gasoline | **18.2** L |

## 5. The Separator

> **Observation 5.1**
>
> **the separator is whether one counts the contents alone or the container with them.The same two fuels stand at 2.727273 by mass of contents, one 6.804613th by volume of contents, and one 6.111111th by mass of system——"hydrogen is the lightest source of energy" is not decided true or false until one says what the count includes.**

> **Observation 5.2**
>
> **placed beside Papers 730 and 326.Paper 730 showed that a resistance one cannot take off sits in the denominator, making the first layer and the second worth different amounts——here a container sits in the denominator and changes the ranking itself.Paper 326 showed that the square-cube "law" is an identity——here too what moves the ratio is what goes into the denominator.**

**Observation 5.3**

**what is not said.The merits of real tanks, the efficiency of fuel cells or engines, safety, filling and boil-off are not treated——what is shown is that the ranking reverses with the way of counting.**

## 6. Census and Closing

1. **120 against 44 MJ/kg (2.727273)** (Section 2): **mass of contents.**
2. **700 bar density 40.413760 kg/m³** (Computation 2.1): **down from 56.579264.**
3. **double the pressure, double the density (2.000000)** (Observation 2.2): **a light start.**
4. **4.849651 GJ/m³** (Computation 3.1): **at 700 bar.**
5. **one 6.804613th of gasoline** (Observation 3.2): **losing by volume.**
6. **one 3.884181th as a liquid** (Computation 3.1): **cooling is not enough.**
7. **6.840000 MJ/kg of system** (Computation 4.1): **fraction 0.057.**
8. **gasoline 41.800000 MJ/kg** (Computation 4.1): **fraction 0.95.**
9. **one 6.111111th** (Observation 4.2): **the core; the direction reverses.**
10. **contents alone or container included** (Observation 5.1): **the separator; Papers 730, 326.**

**Closing**: **The best fuel by mass loses on both volume and mass once the container is counted.Hydrogen gives 120 MJ/kg against gasoline's 44, a factor of 2.727273, yet at 300 K and 700 bar its density is only 40.413760 kg/m³ where an ideal gas would give 56.579264——a gas does not pack under pressure.By volume it gives 4.849651 GJ/m³ against 33.000000, one 6.804613th, and one 3.884181th even as a liquid; counting the container it gives 6.840000 against 41.800000 MJ/kg, one 6.111111th——because the container's mass does not scale with the contents.Carrying 5 kg of hydrogen takes 123.7 L of contents at 700 bar, while the same energy as gasoline takes 18.2 L.The separator is whether one counts the contents alone or the container with them.Placed among the earlier papers——standing beside Paper 730's denominator that cannot be taken off, and showing, as Paper 326 did, that what moves the ratio is the denominator.To be honest——the compressibility factor and the storage fractions are representative, and neither efficiency nor safety is included.**

## References


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