With nanoplasmonics towards fusion

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Energy crisis

Future energy: nuclear fusion
NAPLIFE: aims, results, plans

The good fuel: high energy to mass ratio
Alternatives of the present

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NAPLIFE ZIM 2022 2 / 23
Specific data, available energy

J/mg = MJ/kg

- coal 23; brown coal 18; turf 7; wood 11; biomass 10; hulladék 9; olajpala 20
- oil, PB gas 40; bio-fuel 30; waste 25
- natural gas 47; H 40; biogas 20; waste gas 15
- uranium 460.000; fusion 640.000.000

1 kg U ≈ 20 tons of coal ≈ 0.7 g fusion fuel
The "atomic" force

nuclear techniques

Energy production = gain with losses
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Thermal and equilibrium

ITER magnetic confinement
Direct and sudden

NIF laser shots
D + T fusion

why-s and problems

1. energetic neutrons; 2. global tritium quantity (nuclear power plants)
### Neutronfree fusion

#### High nuclear cross section aneutronic reactions

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Reaction</th>
<th>Energy (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deuterium - $^3$He</td>
<td>$^2\text{D} + ^3\text{He} \rightarrow ^4\text{He} + ^1\text{p}$</td>
<td>18.3</td>
</tr>
<tr>
<td>Deuterium - $^6$lithium</td>
<td>$^2\text{D} + ^6\text{Li} \rightarrow 2\ ^4\text{He}$</td>
<td>22.4</td>
</tr>
<tr>
<td>Proton - $^6$lithium</td>
<td>$^1\text{p} + ^6\text{Li} \rightarrow 2\ ^4\text{He} + ^3\text{He}$</td>
<td>4.0</td>
</tr>
<tr>
<td>$^3$He - $^3$He</td>
<td>$^3\text{He} + ^3\text{He} \rightarrow ^4\text{He} + 2\ ^1\text{p}$</td>
<td>12.86</td>
</tr>
<tr>
<td>Proton – Lithium-7</td>
<td>$^1\text{p} + ^7\text{Li} \rightarrow 2\ ^4\text{He}$</td>
<td>17.2</td>
</tr>
<tr>
<td>Proton – Boron-11</td>
<td>$^1\text{p} + ^{11}\text{B} \rightarrow 3\ ^4\text{He}$</td>
<td>8.7</td>
</tr>
<tr>
<td>Proton – Nitrogen</td>
<td>$^1\text{p} + ^{15}\text{N} \rightarrow ^{12}\text{C} + ^4\text{He}$</td>
<td>5.0</td>
</tr>
</tbody>
</table>
Electrons in the fusion

PEP process, Widom-Larsen (wiki)

\[ p + e^- \rightarrow n + \nu_e \ (-1.25 \text{ MeV}), \quad p + n \rightarrow d + \gamma \ (+2.22 \text{ MeV}) \]

Widom–Larsen theory

From Wikipedia, the free encyclopedia

The **Widom-Larsen theory** is a proposed explanation for supposed Low Energy Nuclear Reactions (LENR) developed in 2005 by Allan Widom and Lewis Larsen. In the paper describing the idea, they claim that ultra low momentum neutrons are produced in the cold fusion apparatuses\(^2\) during weak interactions when protons capture "heavy" electrons from metallic hydride surfaces.\(^3\) One source has held that it is "unlikely the electron energy threshold for neutron production can be reached in a metal lattice system without a substantial energy input".\(^4\)

The idea was expanded by Yogendra Srivastava together with Widom and Larsen in 2014, who went on to propose that it could be an explanation for neutrons observed in exploding wire experiments, solar corona and flares, and neutron production in thunderstorms.\(^5\) However, unrealistic concentrations of free electrons are needed for the neutron yield to be a significant component of thunderstorm neutrons, discounting the explanation.\(^6\)
NAPLIFE individual features

1. Plasmonic collectivity, energy concentration, threshold lowering, lifetime cca. 20 – 30 fs
2. Far from equilibrium, lightspeed, simultaneous ignitions
3. Nanoantennas in target, ultrashort, high contrast laser pulses ($10^6$, 40 fs @ Wigner)
4. Energy balance and fusion products at low energy: microcraters, $D/(2D+H)$
Nanofusion

plasmons: barrier reduced, energy hot spots
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Fusion cross section
when electrons screen the Coulomb barrier (Wong+Shih 2022)

Formula \( \sigma(E, U_s) = \frac{S(E+U_s)}{E+U_s} \left[ e^{\pi \sqrt{\frac{2.29 \text{MeV}}{E+U_s}}} - 1 \right]^{-1} \).

Figure 1. \( p-^{11}\text{B} \) cross section as function of particle energy for the screening electron densities up to \( U_s = 45 \) keV. The cross section below \( E = 1 \) keV grows over 10 orders of magnitude (from \( 10^{-44} \) to \( 10^{-34} \) m\(^2\)) when \( U_s \) increases from 10 to 45 keV.
Near-field enhancement with individual plasmonic nanoresonators & Kroomium nanoparticles

- **core-shell**
  - Without Kroomium NP: E/E₀~17.9 (R = 1 nm), E/E₀~58.7 (R = 5 nm)
  - With attached Kroomium NP: E/E₀~24.0 (R = 1 nm), E/E₀~33.9 (R = 5 nm)

- **nanorod**
  - Without Kroomium NP: E/E₀~42.6 (R = 1 nm), E/E₀~112.0 (R = 5 nm)
  - With attached Kroomium NP: E/E₀~57.0 (R = 5 nm)

- **triangle**
  - With attached Kroomium NP: E/E₀~30 (R = 10 nm), E/E₀~47 (R = 5 nm), E/E₀~105.2 (R = 5 nm)
Kinetic model: PIC

Single nanorod time evolution (I. Papp)

Evolution of ionised Hydrogen around the nanoantenna

- electrons
- H atoms
- protons
- H-electrons

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Scattered nanorod patterns (A. Bonyar, M. Veres)
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NAPLIFE CRATER
Craters w/o Au
(J.Kaman, A.Szokol)

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Crater volume

The analysis of the crater volumes – in 5 different points for every energy and target

Vav (nm³) vs Laser pulse energy (mJ)

UDMA-X
UDMA-Au1
UDMA-Au2
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NAPLIFE RAMAN
UDMA - TEGDMA copolymer (M. Veres)

Figure 1. Chemical structure of UDMA monomer together with the selected part used for further modeling and calculations.

Figure 2. Optimized (B3LYP/6-311++G(d,p)) geometry of UDMA model (C\textsubscript{1}H\textsubscript{2}-C\textsubscript{2}H\textsubscript{2} and C\textsubscript{3}H\textsubscript{2}-C\textsubscript{4}H\textsubscript{2} groups are in anti and gauche conformational states, respectively).
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NAPLIFE Raman

Raman signals: vibration of molecular bonds (Veres)

UDMA-Au-Irrad - UDMA-Au-Ref
UDMA-Au-25
UDMA-Au-15
UDMA-Au-10
UDMA-Au-5

Raman intensity, a.u.
Raman shift, cm⁻¹

UDMA-X-Irrad - UDMA-X-Ref
UDMA-X-25
UDMA-X-15
UDMA-X-10
UDMA-X-5

Raman intensity, a.u.
Raman shift, cm⁻¹

Ilaser > 10¹⁶

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Raman signals: molecular vibrations from various spots in the crater

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NAPLIFE LIBS

LIBS: atomic ionisation → D/H (Aladi)
Energy production = gain with losses
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NAPLIFE LIBS++

LIBS: kinetic energy estimate (Kroó, Biró)

Delay times $\rightarrow$ velocity distribution (rough proxy)

\[ t_{\text{max}} \approx 0.6 \, \mu \text{s}, \quad t_{\text{light}} \approx 0.13 \, \text{ns}, \quad t_{2\rightarrow3} \approx 2 \, \text{fs}. \]
\[ v_D \approx 70 \, \text{km/s}, \quad E_{D,\text{kin}} \approx 50 \, \text{eV}, \quad \frac{v_D}{c} \approx 2 \cdot 10^{-4}. \]
Our further plans:

- Nuclear detection (CR39)
- ELI cooperation (similar and bigger lasers)
- Variation of the shooting geometry
- Nanoparticles and medium matter variations
- Energy, deuteron and $\alpha$ observation