Dual Fluid Energy

Reinventing Nuclear.

Dual Fluid Energy Inc., Vancouver

Content

A concept beyond Generation IV

Reactor development – where we are

1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010 | 2020 | 2030

Generation I

Early Prototype Reactors

- NPP Shippingport
- Dresden, Fermi I
- Magnox

Generation II

Commercial Power Reactors

- LWR, PWR, BWR
- CANDU
- WWER/RBMK

Generation III

Advanced LWRs

- ABWR
- System 80+
- AP600
- EPR

Generation III+

- Near-term deployment
- Evolutionary designs, offering improved safety

Generation IV

New designs targeting at:
- Inherent safety
- Minimal waste
- Proliferation resistance

Sodium-cooled fast reactor SFR

Very high temperature reactor VHTR

Lead-cooled fast reactor LFR

Molten-salt reactor MSR

Ahead of fusion research. Most function principles proven in the past.

Main problem with Generation IV: Economy. Most systems still use solid fuel rods > Expensive fuel cycle!
Exception: Molten salt reactors (MSR)

Generation V: The unique Dual Fluid principle

- **Liquid fuel**
  Any fissionable material:
  - Thorium
  - natural Uranium
  - processed nuclear waste
- **Coolant**
  liquid lead
- **Operating temperature** 1000°C
- **Patents**
  - Reactor design **Link**
  - Liquid metal fuel (pending) **Link**

Fuel cycle

Coolant cycle

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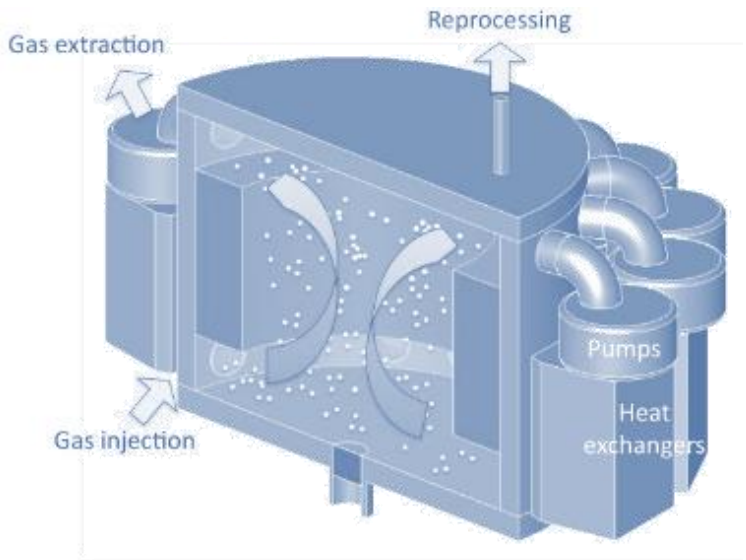
Why is the Dual Fluid Reactor not a MSR?

Molten Salt Reactor (MSR) e.g. SAMOFAR

Single fluid

- Homogeneous core
- Heat removal by salt
- Fuel limited to salt



Dual Fluid Reactor

Two fluids

- Heterogeneous core
- Heat removal by second fluid
- Fuel liquid less constrained

The double function of fuel providing and heat removal in the MSR limits its power density.
The Dual Fluid technology overcomes this limitation.

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Fuel and lead at 1000°C

How is this possible?

Outside the nuclear industry suitable materials are known for a long time

Focus of nuclear industry so far was on finding cheap materials (usually steel alloys) that are corrosion resistant

Dual Fluid can afford **expensive** materials due to the low material consumption

Possible materials: Refractory metal alloys and ceramics

1. Silicon Carbide (SiC)
2. Zircon Carbide (ZrC)

The Dual Fluid principle: Full control, self-regulating

Highly negative temperature coefficient due to thermal expansion of liquid fuel

- Temperature rises → Fission rate and heat production drop
- Temperature drops → Fission rate and heat production rise

Temperature is held homeostatic at 1000 °C
- No material stress from power change

Power is fully regulated by heat extraction
- Load-following operation in the grid

Qualified for rapidly changing demand
- Process heat for chemical plants

Reactor **can be on "stand by"** in a critical state at zero power output → Safe operation mode

No mechanical regulation equipment needed

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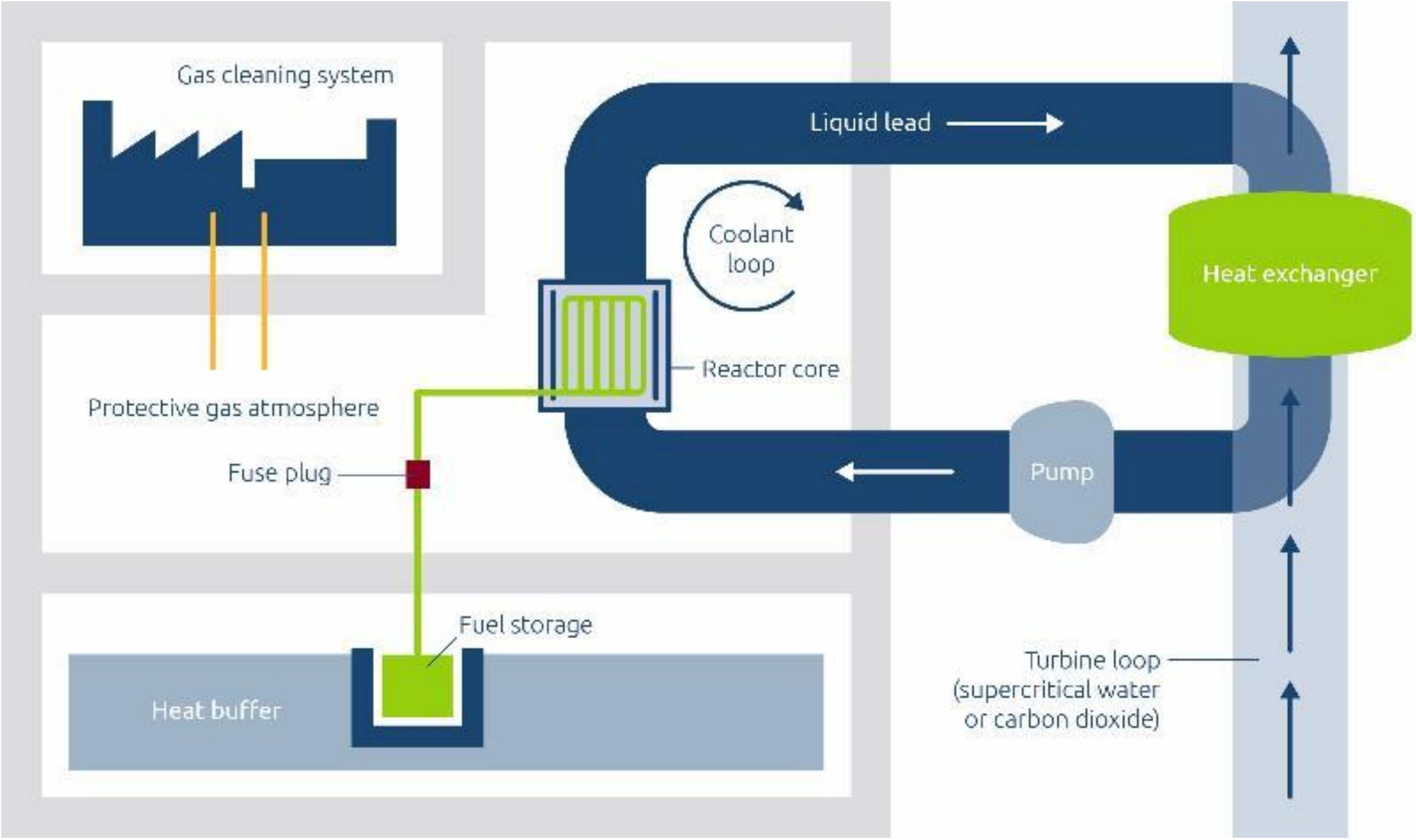
DF300 power plant (SMR): Properties & benefits



- Fuel exchange intervals at full power up to 30 years
- Burnup up to 200 MWd/kg_{HM}
- Can fully utilize nuclear waste when combined with external recycling unit
- Core vessel and fuel storage tank replacable
- Electricity generation with ~ 50% efficiency, e.g. using supercritical media (scH_2O, $scCO_2$)

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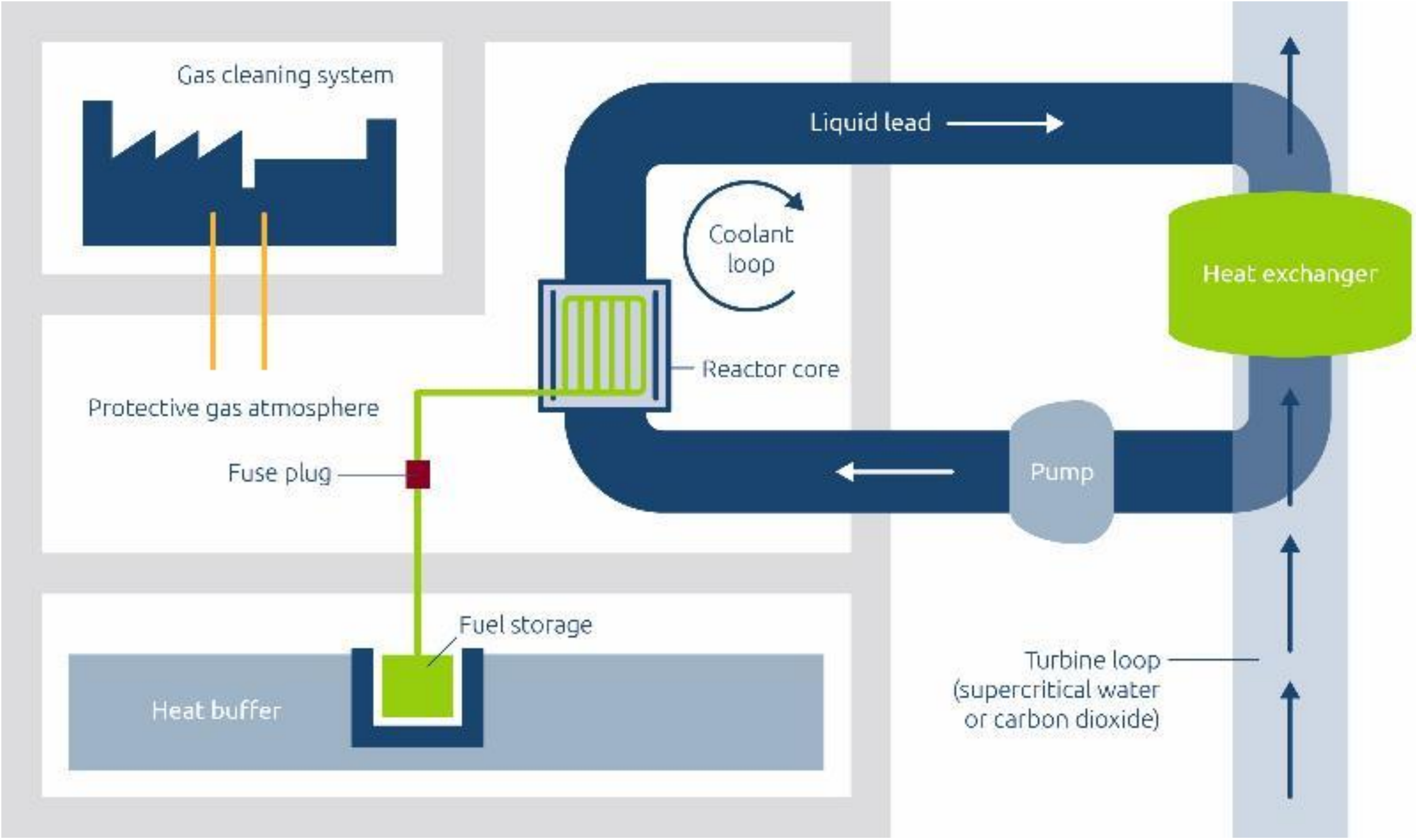
DF300 power plant: Safety



- **Self-regulating,** homeostatic system
- Nuclear section of plant **underground** for enhanced safety
- Longterm decay heat reduced in the core. Decay heat is passively removed > Overheating (**Fukushima**) impossible
- Core drained > chain reaction ends automatically > Uncontrolled chain reaction (**Chernobyl**) impossible

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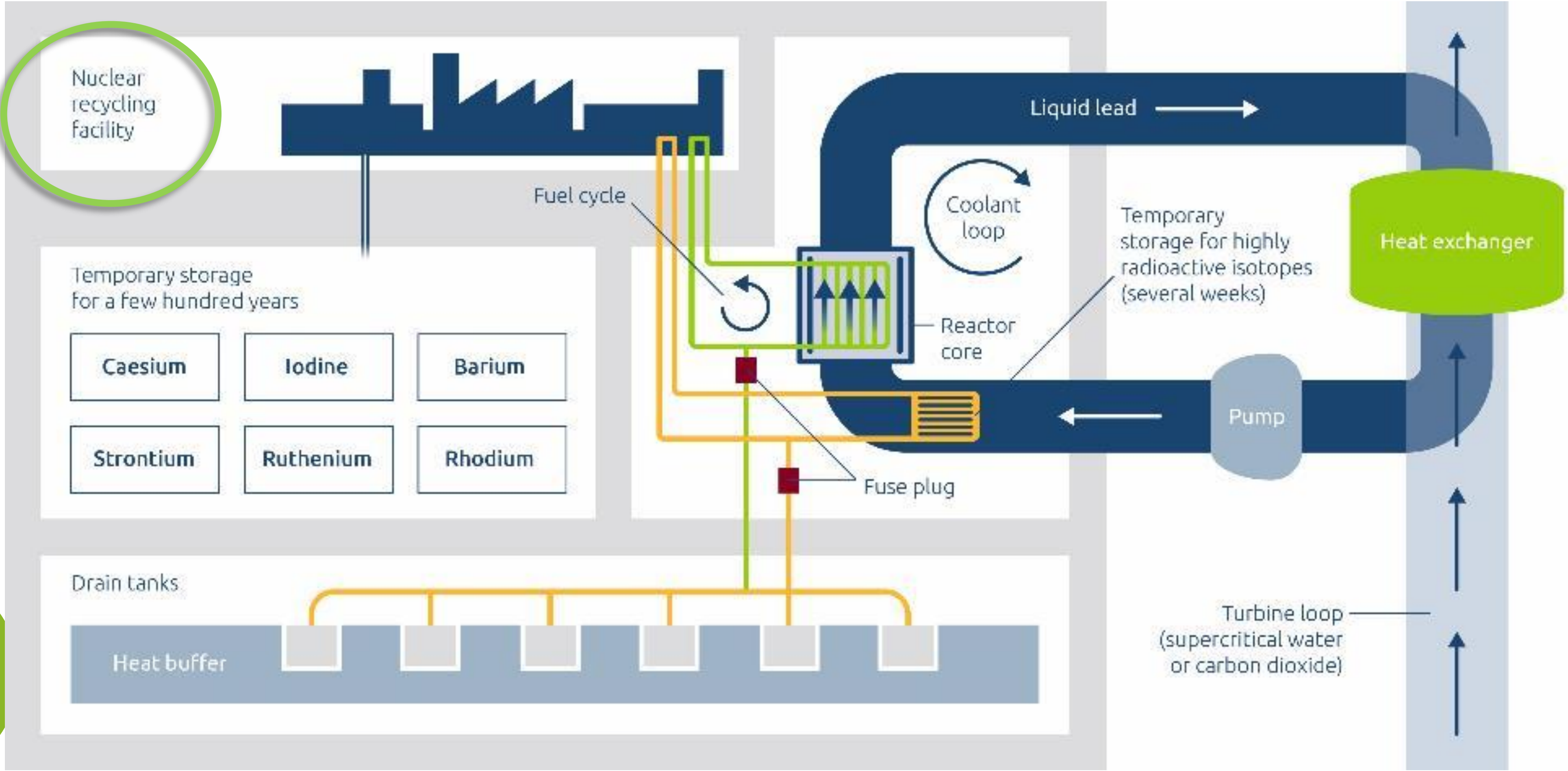
DF1500 power plant: Closing the fuel cycle

- Natural Uranium
- Depleted Uranium
- Thorium
- Used fuel elements

- Fission products
- Med. radioisotopes
- Fissile material

CLOSED FUEL CYCLE



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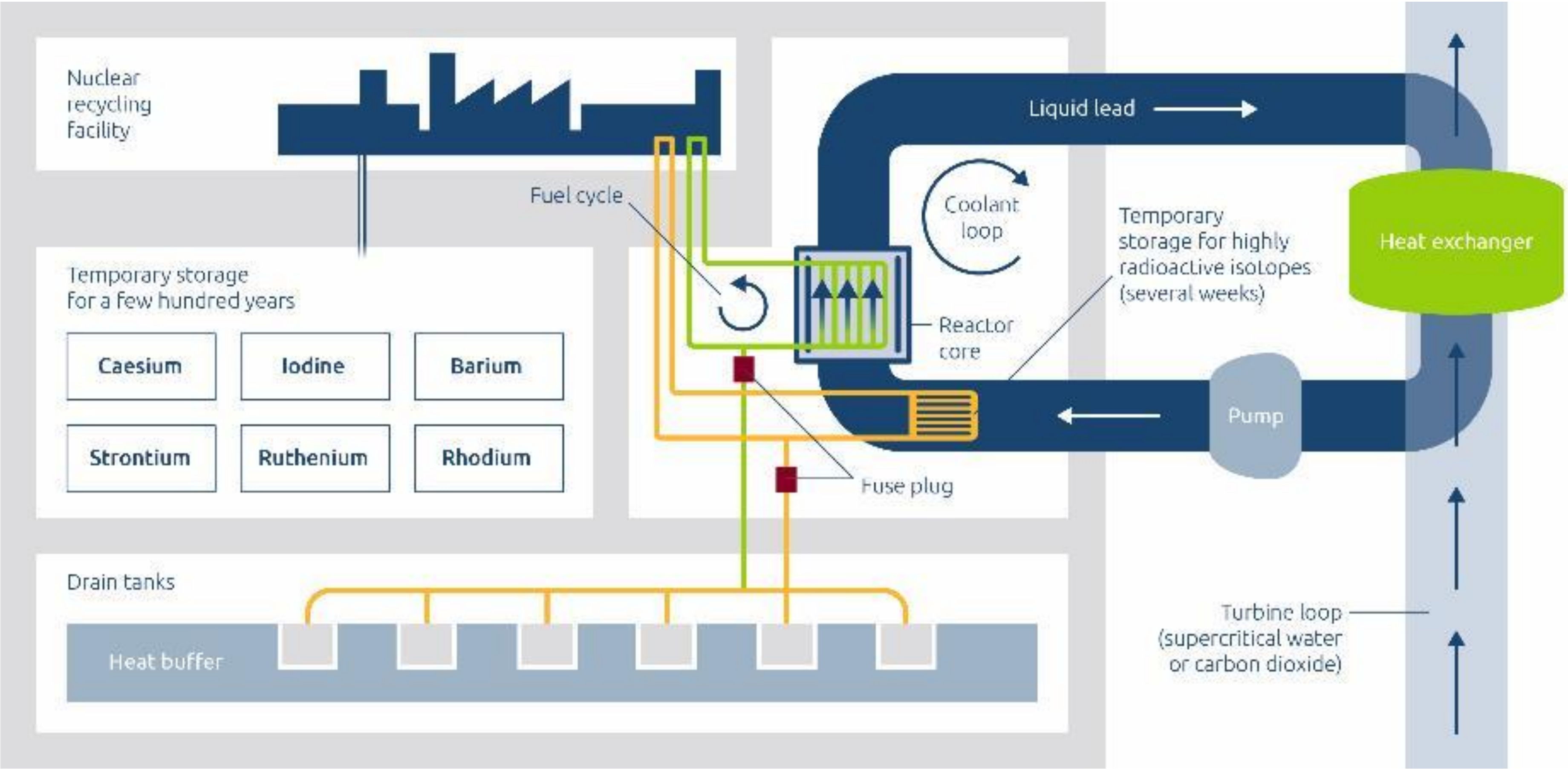
DF1500 power plant: Properties & benefits



- **Fission products storage** on-site > Toxicity level below natural uranium after a few hundred years
- **Rare metals** available pure after a few hundred years
- Optional high-temperature **process chemistry** at 1,000 °C
- **Electricity generation with >50% efficiency**, e.g. using supercritical media (scH_2O, $scCO_2$)

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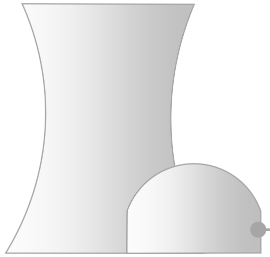
Nuclear waste recycling with Dual Fluid

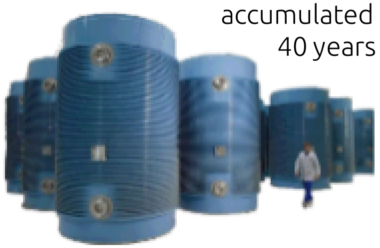
Step 1
Pre-conditioning Plant



Today's Light Water Reactor (1400 MW_e)

(All amounts are for the heavy-metal (HM) part. Tons are metric tons)

25 tons / year



Per reactor 1,000 tons, accumulated over 40 years

- Dismantling of the fuel elements
- Chopping of the pellets
- Conversion of the oxides into chlorides

Step 2
Partitioning Plant

Chloride salts

Pyrochemical Processing Unit
Max. throughput:
500 tons / year

Mass reduction:
Factor 33 within 2 years

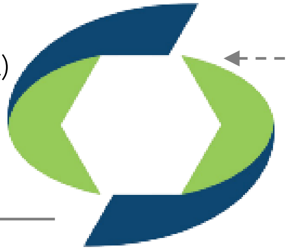
Fission product storage
30 tons
Thereof 3 tons long-lived
Max. a few hundred years of storage time

Energetically not usable

Actinide storage
960 tons Uranium
9 tons Plutonium
1 ton minor Actinides

Energetically usable

Step 3
Transmutation in reactor core



Dual Fluid core
3 GWth (1,5 GWel)

Energetic usage:

- High temperature heat
- Electricity generation

Incineration of actinides in the Dual Fluid core

Consumption: 1.2 tons / year
(Range of the waste for many hundred years)

Optional additional transmutation of up to 0.3 tons / year long-lived fission products

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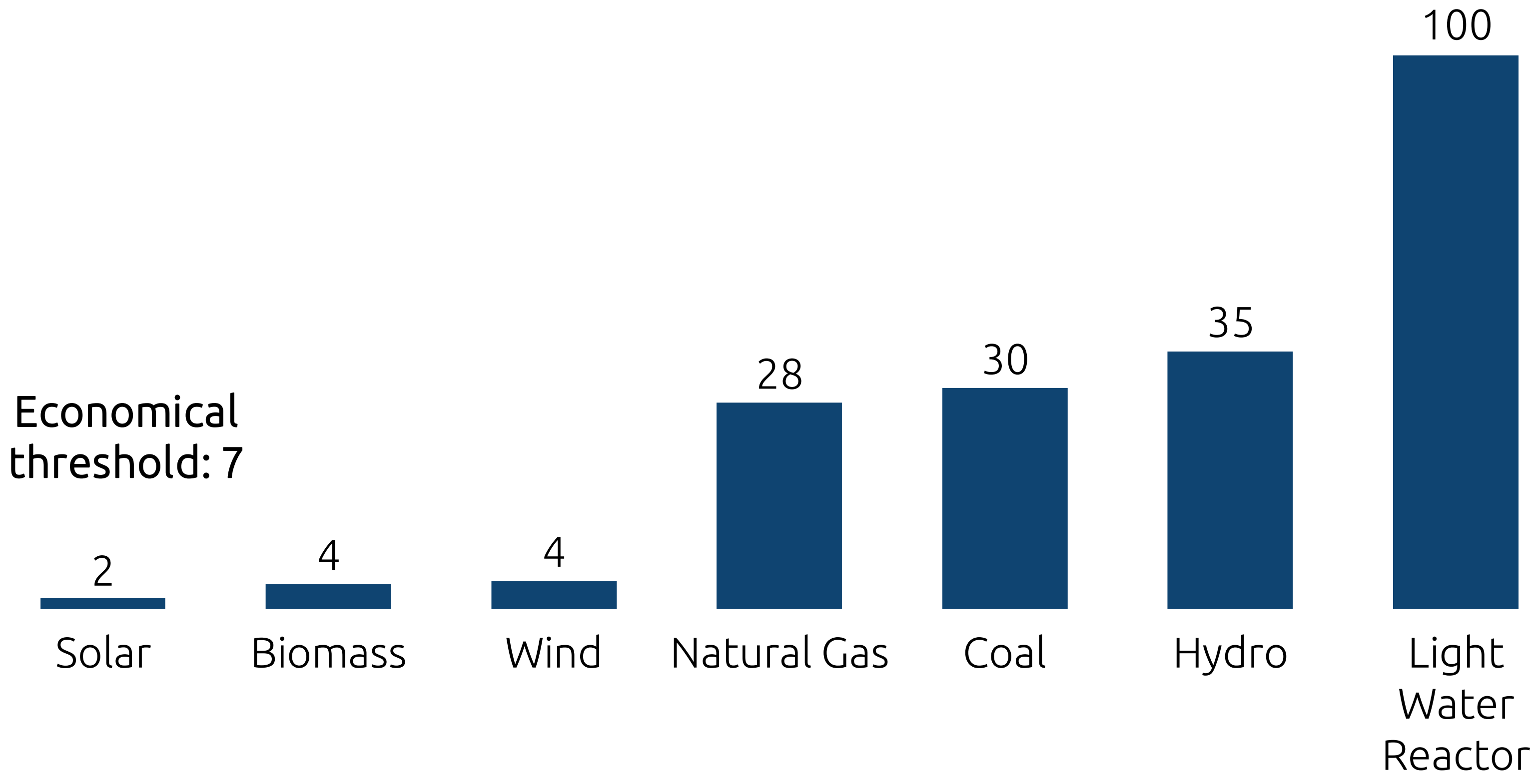
Efficiency, costs and applications

Energy Return of different energy generation types

The Energy Returned on Investment[1] (EROI) = Ratio of the amount of usable energy delivered to the amount of energy required (for construction, fuel, maintenance, safety, dismantling, etc. of a power plant)

$$\text{EROI} = \frac{E\ \text{out}}{E\ \text{in}}$$



1. Literature: Daniel Weißbach et al, Energy 52 (2013) 210: Energy intensities, EROIs, and energy payback times of electricity generating power plants

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Energy Return: Do today´s reactors perform well?

The fission of a uranium nucleus releases **100 million times more** energy than the combustion of a hydro/carbon atom. **But:** Today´s reactors deliver **only three times more** energy than coal-fired power plants – per unit of energy input.

Energy release uranium nucleus:
200,000,000 eV

↕

Energy release hydro/carbon atom:
2 eV

What's going wrong here?

Energy return light water reactor:
EROI 100

↕

Energy return coal power plant:
EROI 30

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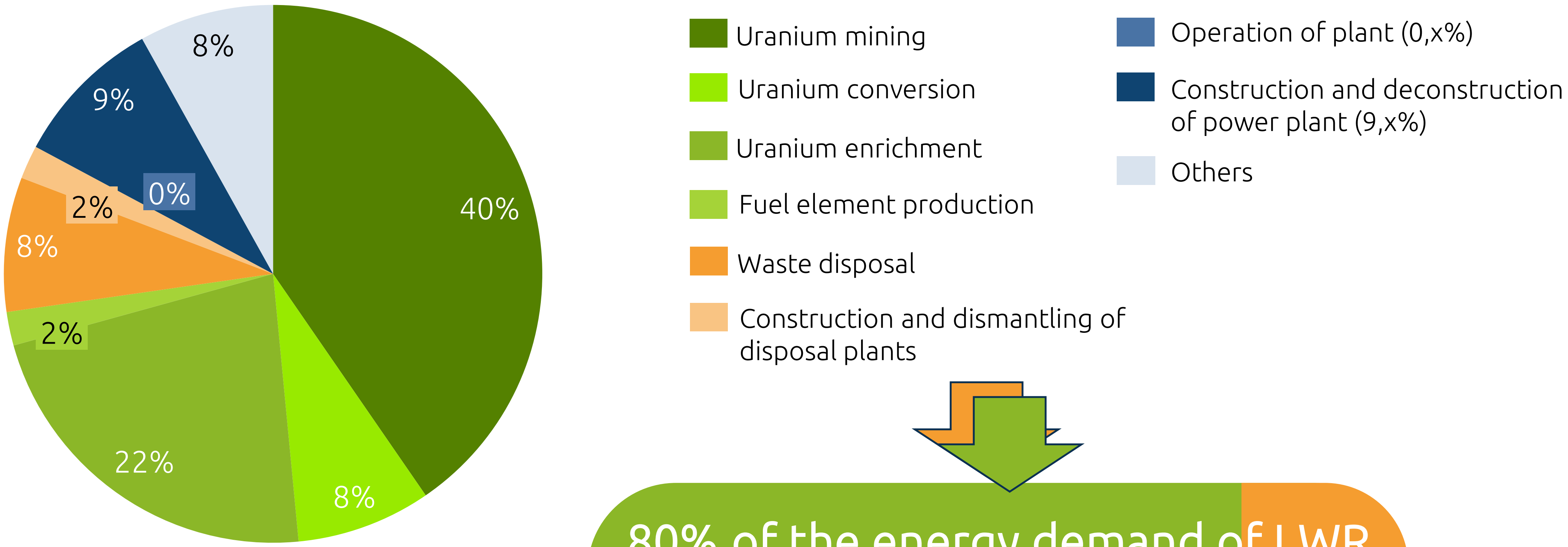
Why don´t LWR perform well? – It´s the fuel cycle

Contributions to the energy demand in the nuclear power production, for a typical light water reactor (LWR)*

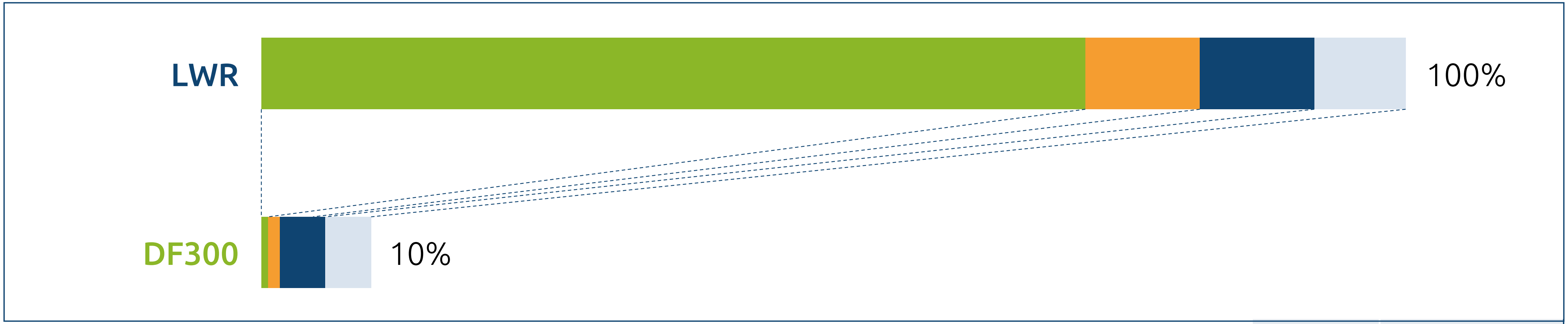


80% of the energy demand of LWR is related to the fuel cycle

*Source: Vattenfall, EPD Forsmark 2009/10

DF300: Optimized fuel cycle, less material

Energy expenditures for the light water reactor vs. Dual Fluid DF300 **(lifecycle analysis)***



	LWR	DF300
Fuel procurement and refining	72	0.56
Waste disposal, (de-)construction + dismantling of disposal plants	10	1
Operation, (de-)construction + dismantling of power plant	10	4
Other	8	4

*All values are approximations, based on Vattenfall / own calculations

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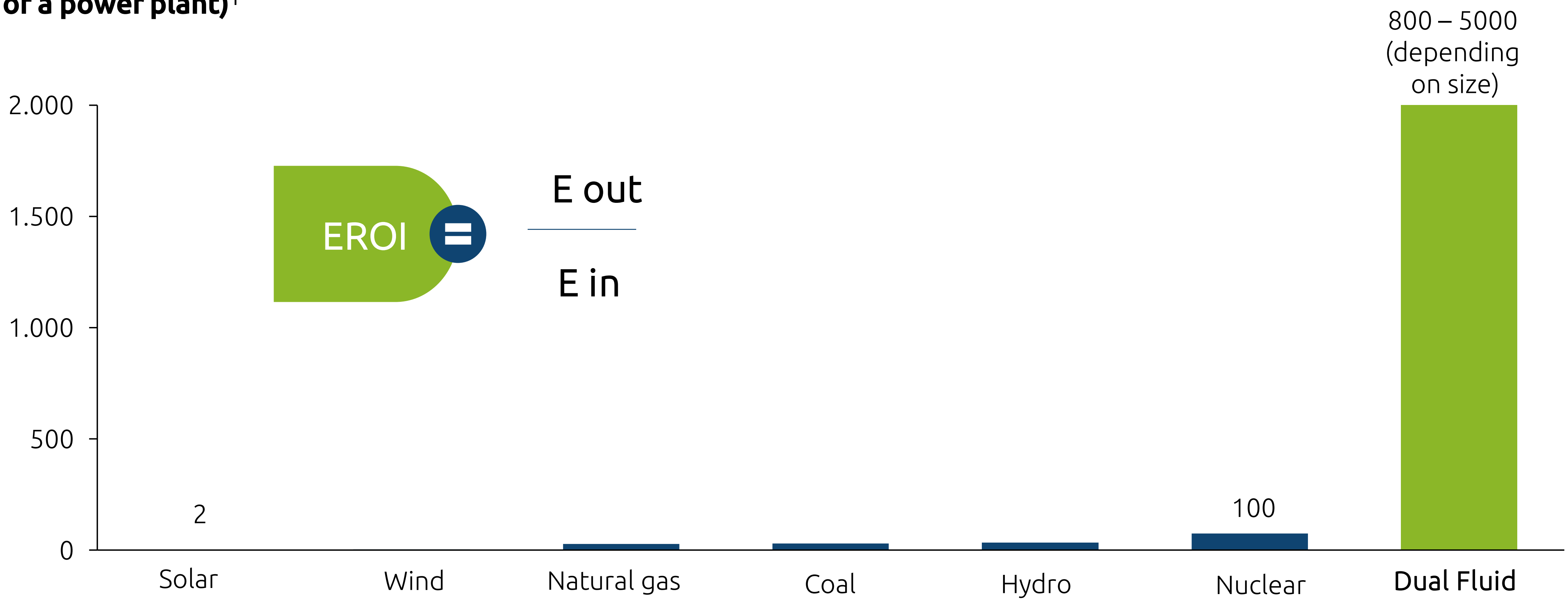
Dual Fluid Energy Return (EROI)

Energy Returned on Investment (EROI) = Ratio of the amount of usable energy delivered to the amount of energy required (for construction, fuel, maintenance, safety, dismantling etc. of a power plant)[1]



1. Literature: Daniel Weißbach et al, Energy 52 (2013) 210: Energy intensities, EROIs, and energy payback times of electricity generating power plants

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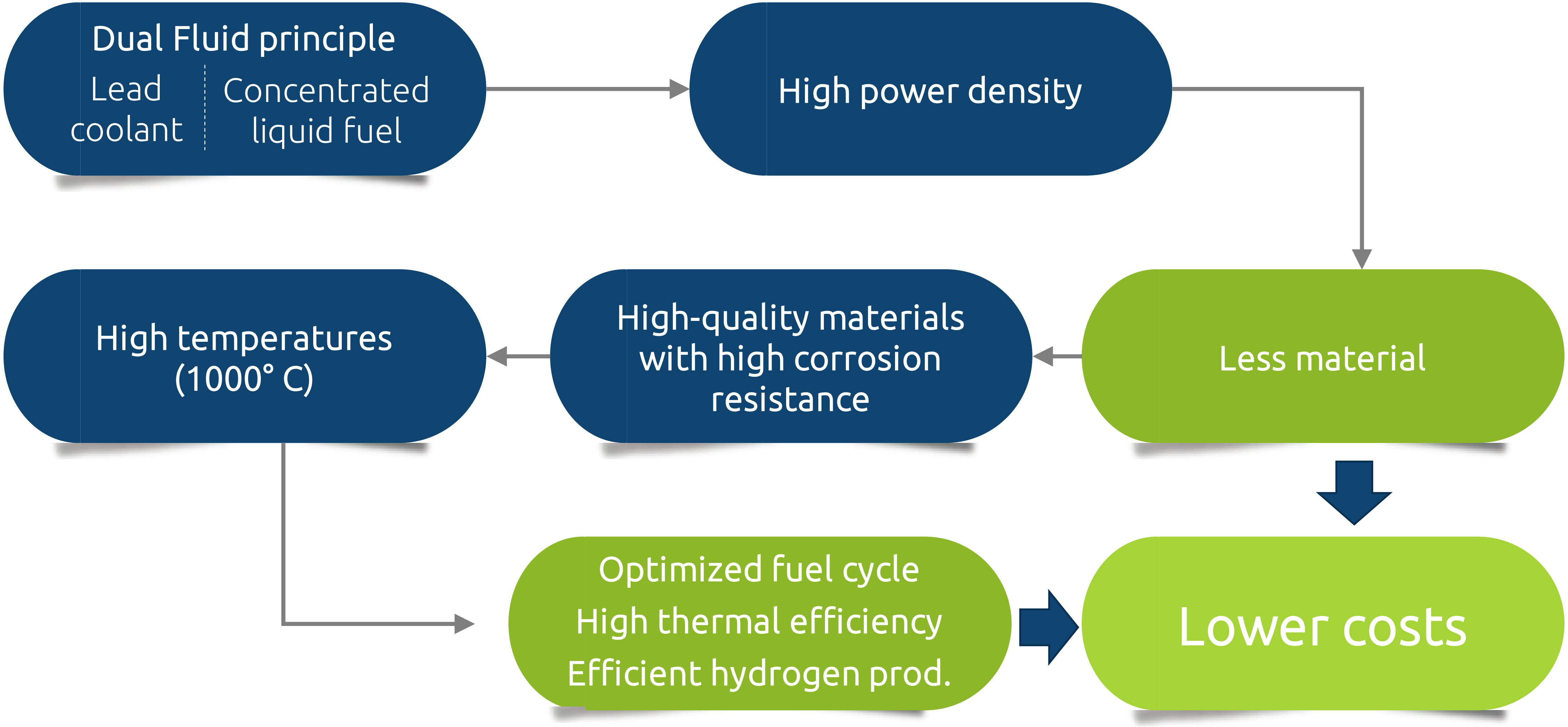
How does the Dual Fluid principle reduce costs?



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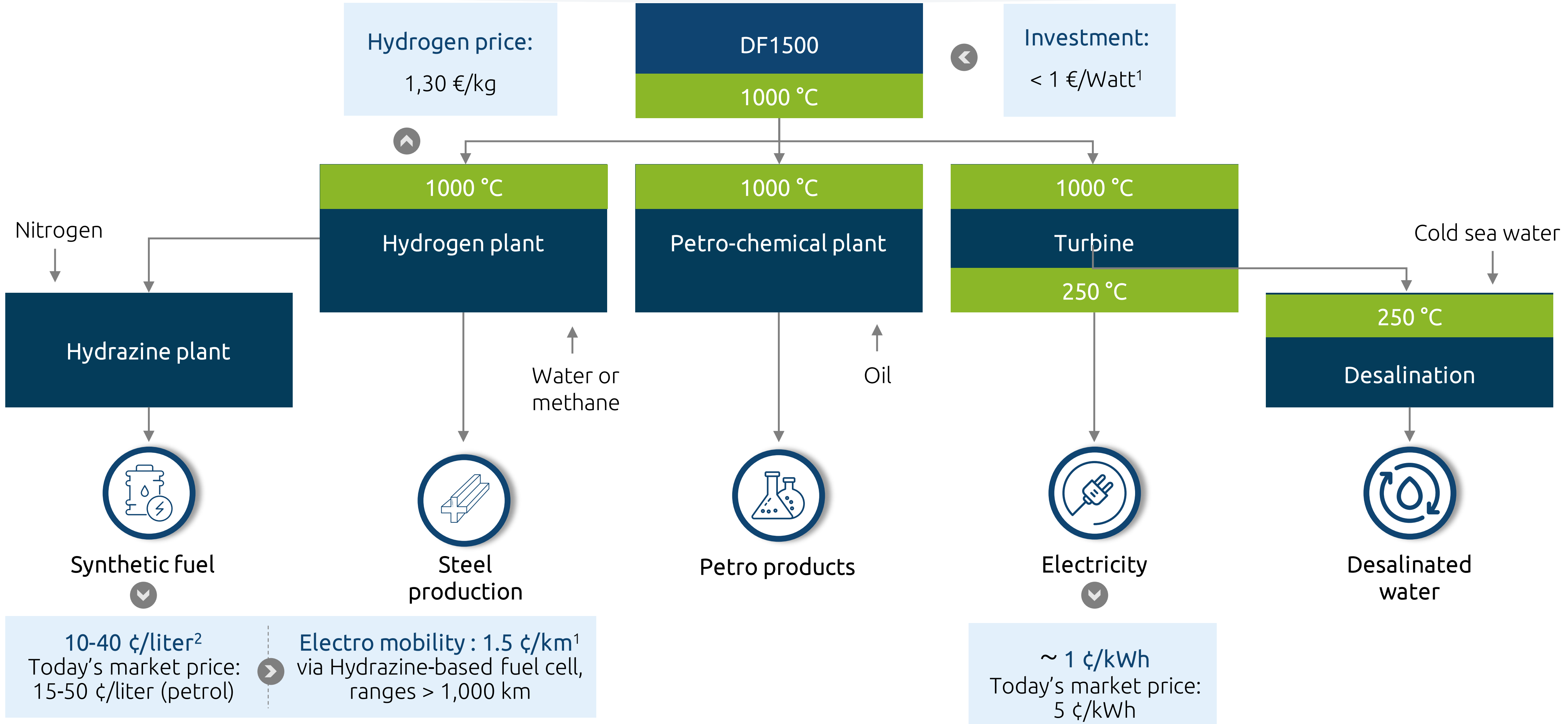
Dual Fluid 1500: Applications and costs



1. Overnight costs; 2. Gasoline equivalent

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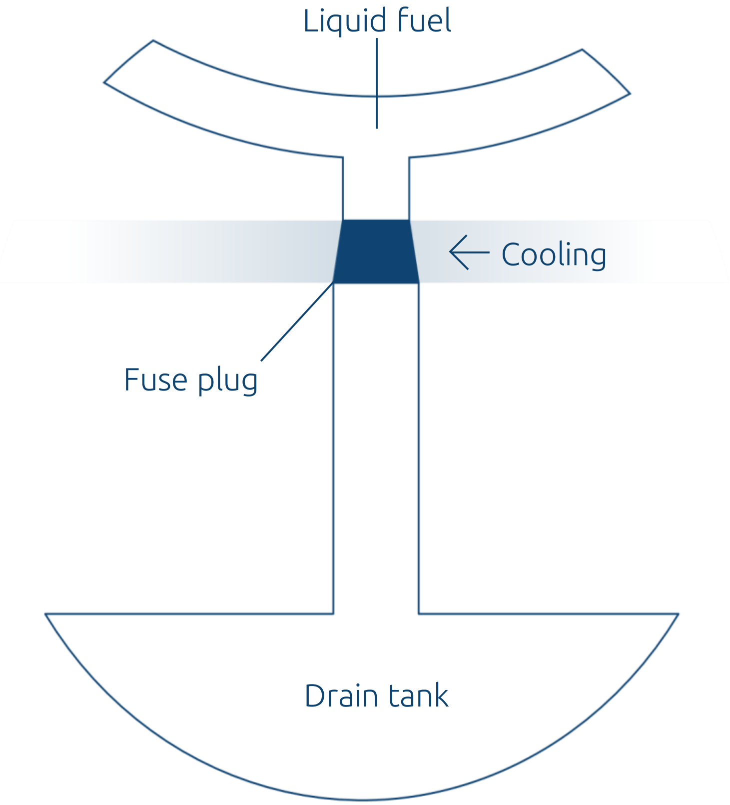
Summary

Why is Dual Fluid technology walk-away-safe?

It is totally self-regulating

Fuel expands when temperature rises

- → Fission rate decreases, heat production subsides
- → Automatic cool-down
- → Power excursion, explosions or “meltdowns” are physically impossible



Fuse plugs provide additional safety

Safety system for overheating (caused by manipulation)

- → Fuse plug melts
- → Fuel automatically flows into safe drain tank

- → **Walkaway safe; no danger in the case of human error/misguided action**

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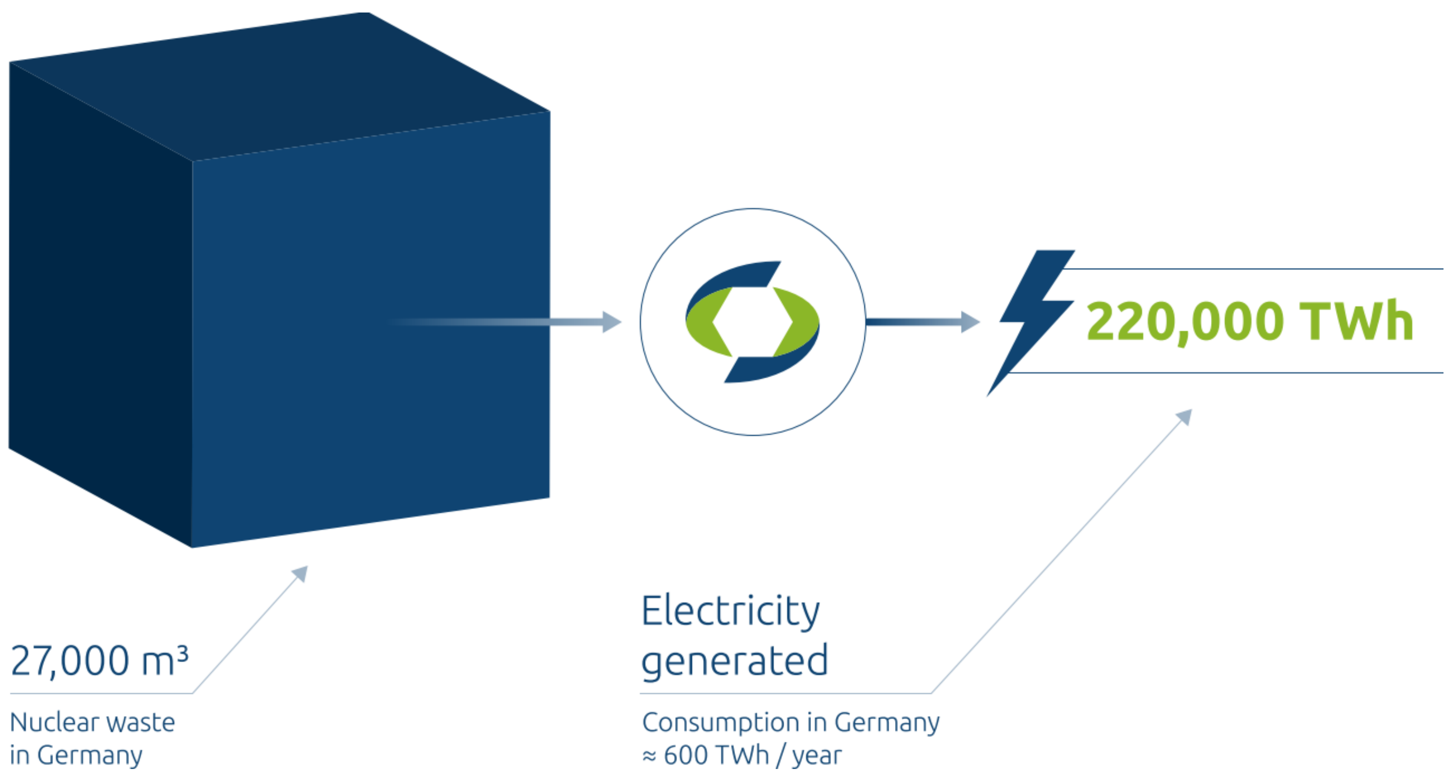
How does Dual Fluid solve the waste problem?



- **Nuclear waste is recyclable material**
  The Dual Fluid recycling facility processes exisiting nuclear waste to fissionable material and mostly short-lived waste.
- **No final repository required**
  After just a few hundred years, the residual materials become less toxic than natural uranium.
- **Full use of fuel**
  The nuclear fuel is fully used – made possible by the integrated or external recycling process (DF1500 / DF300).

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What about proliferation?

To obtain weapons-grade Plutonium, **the cheapest way is to use other technologies than a nuclear reactor** (see North Korea: no NPP, but nuclear weapons).

To extract materials suitable for weapons from a Dual Fluid power plant, **it would have to be modified completely.** Regulators would notice this immediately.

As the Dual Fluid technology can also utilize plutonium from old nuclear weapons, **it can contribute to disarmament.**

Why is Dual Fluid superior to other GenIV concepts?

Solution to waste problem: New reactor concept with fully closed fuel cycle

Total passive safety through simple physical laws

Higher efficiency in power generation than any known technology

Power generation **costs lower than fossils**

Qualified for **rapidly changing power** demand

Low-cost hydrogen -production above 900°C possible

Publications

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Selected Publications

Jakub Sierchuła et al, Int J Energy Res. 43 (2020) 3691: „Determination of the liquid eutectic metal fuel Dual Fluid Reactor (DFRm) design – steady state calculations"

Dominik Böhm et al, Acta Physica Polonica B 51 (2020) 893: "New methods for nuclear waste treatment of the Dual Fluid reactor concept"

Chunyu Liu et al, Metals 10 (2020) 1065: "Thermal Hydraulics Analysis of the Distribution Zone in Small Modular Dual Fluid Reactor"

Daniel Weiβbach et al, Int. J. Energy Res. (2020)1: "Dual Fluid Reactor as a long-term burner of actinides in spent nuclear fuel"

Sang-in Bak et al, The European Physical Journal Plus 134 (2019) 603: "Design of an accelerator-driven subcritical dual fluid reactor for transmutation of actinides"

Xiang Wang et al, Int J Energy Res. 42 (2018) 4313-4334: „Steady-state reactor physics of the dual fluid reactor concept"

Thomas J. Dolan: „Molten Salt Reactors and Thorium Energy", Woodhead Publishing, 2017

Xiang Wang, Dissertation 2017: „Analysis and Evaluation of the Dual Fluid Reactor Concept"

Armin Huke et al, Annals of Nuclear Energy 80 (2015) 225: „The Dual Fluid Reactor – A novel concept for a fast nuclear reactor of high efficiency",

Daniel Weißbach et al, Energy 52 (2013) 210: „Energy intensities, EROIs, and energy payback times of power plants"

Armin Huke et al, Conference Paper from the 19th Pacific Basin Nuclear conference (PBNC 2014), Vancouver: The Dual Fluid Reactor - A New Concept For A Highly Effective Fast Reactor.

Jan-Christian Lewitz et al, atw 65 (2020) 145: The Dual Fluid Reactor – An Innovative Fast Nuclear-Reactor Concept with High Efficiency and Total Burnup

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